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Laser Hazard Analysis Software (LHAZ)
VERSION 5

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NOTICE AND SIGNATURE PAGE

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14. ABSTRACT

This document describes the AFRL/RHDO produced Laser Hazard Analysis Software (LHAZ) version 5.0. LHAZ 5.0 is a Microsoft Windows desktop analysis tool. It implements the ANSI Z136.1-2007 version of the ANSI Z136.1 standard. It is a tool for trained laser safety officers to predict laser classification, maximum permissible exposures (MPE), nominal ocular hazard distances (NOHD), Optical Density (OD) requirements for laser eye protection (LEP) or laser protective materials for both direct and indirect laser exposures. LHAZ 5.0 is written in C# as a Plug-in to the AFRL/RHD Application Framework. The LHAZ 5.0 computational engine is the Laser Threat Modeling Components (LTMC) library. LTMC is a reusable C++ Library.

15. SUBJECT TERMS

ANSI Z136.1, MPE, Laser, Laser Eye Protection, LEP, Optical Density, OD, LHAZ, LTMC, NOHD, AFRL/RHDO, AFRL/HEDO, Framework, Plug-in, Plugin

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1.   INTRODUCTION

LHAZ version 5 is a full-featured, integrated, laser hazard assessment program. It combines a maximum permissible exposure (MPE) calculator and American National Standards Institute (ANSI) classification[1] routine with hazard assessment and range equations worksheets to make laser safety assessment and hazard control easier for laser safety officers, managers, and other key decision makers.

LHAZ strictly adheres to the most recent version of the ANSI Standard Z136.1, ANSI Z136.1-2007[1].

Please note, however, LHAZ is not an "expert system." **It is not a replacement for a knowledgeable laser safety officer**. It is only a tool to help laser safety officers in the performance of their duties. LHAZ 5.0 assumes that the user has a basic working knowledge of the ANSI Z136.1 Standard[1].

2.   HARDWARE REQUIREMENTS

To run this program, you need a PC with:
- Microsoft Windows XP with .NET version 1.1
- Approximately 20 MB of free Hard Drive space
- A display capable of at least a 1024x768 resolution.

3.   GETTING STARTED

There are several ways to learn LHAZ on your own. Experienced laser safety officers will find the program fairly self-explanatory and may wish to learn by trial and error. We suggest that you read through this guide with the program running in front of you. This way, you can follow along on the computer and execute the examples in the guide. Whichever way you decide to approach this program, **please read the guide!**

3.1   INTENDED AUDIENCE

LHAZ is not a replacement for a knowledgeable laser safety officer; it is only intended as a tool to help the laser safety officer. As such, both the guide and the program are intended for an audience that is already familiar with laser systems and laser safety.

3.2   AFRL/RHD APPLICATION FRAMEWORK OVERVIEW

Those familiar with AFRL/RHDO research and analysis capabilities will recognize that their most widely distributed analysis tool is the Laser Hazard Analysis Software application known as LHAZ. The typically delivered LHAZ 4.x Standard Edition application encapsulates the data and methodologies encapsulated in the ANSI Z136.1 (2007)[1] standard and also provides a propagation model and hazard distance computation model. Many may not be aware that LHAZ also comes in a professional edition which includes Vision Effects, ED50, LELAWS, and a laser system database. As the AFRL/RHDO development team added and extended LHAZ, they quickly realized that the basic LHAZ application was not originally designed for easy extensibility. One common theme that came up every time LHAZ was extended was the need to "re-plumb" the wiring to gain access to laser parameters and other common functionality. This

drove the understanding that what was really needed was a plug-in based architecture that would allow common functionality to be used by any new analyses without duplication.

The time saved on not re-implementing common functionality is time available to focus on the primary task of implementing the analyses themselves. The AFRL/RHD Application Framework provides a developer with just such a capability by encapsulating common user interface features in an easy to use library. Developers write "plug-ins" to the framework that focus on providing the user with parameters for the analyses, called "Properties", and "Analysis Windows" which present the user with the results of the analyses.

3.2.1   Assembly Architecture

The AFRL/RHD Application Framework is a Microsoft .NET application. It consists of these assemblies found in the bin folder:

- HEDO_AppFramework_Client.exe
- HEDO_AppFramework.dll
- PropertyGridHelper.dll
- RichTextEditor.dll
- MagicLibrary.dll
- ZedGraph.dll

The key assembly in the ones listed above is the HEDO_AppFramework.dll. As of this writing, the version number for the framework is 2.5.0.38. In addition to these standard assemblies for the framework, the LHAZ Plugin requires these assemblies:

- LHAZ_Plugin.dll
- LTMC_Adapter.dll
- LTMC.dll

3.2.2   Starting the Framework

To start the application, run the HEDO_AppFramework_Client.exe found in the bin directory. When the program starts, it first opens a console window that is used for occasional debugging output. It also creates a dialog window that shows the plug-ins loaded from the bin directory.
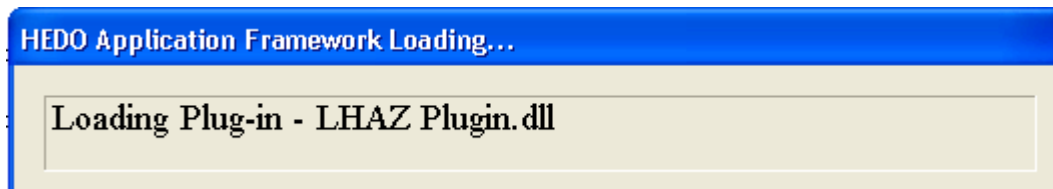
Application Loading Dialog

If there are no plug-ins loaded, the framework will display this "About Window" that says that no plug-ins were loaded. The standard installation of LHAZ 5 places the plug-in dll's, along with their dependencies, in their proper place in the bin directory. If you do see this window because no plug-ins were loaded, re-install LHAZ 5.
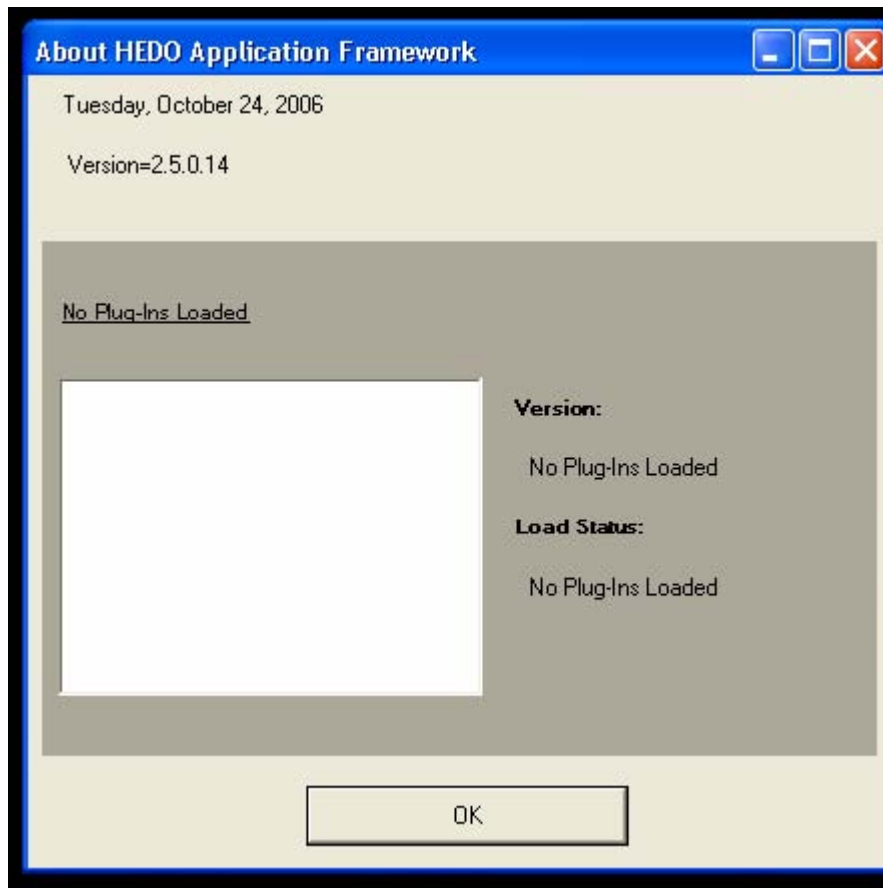
About Dialog (No Plug-ins)

3.2.3 Menus and Window Layout
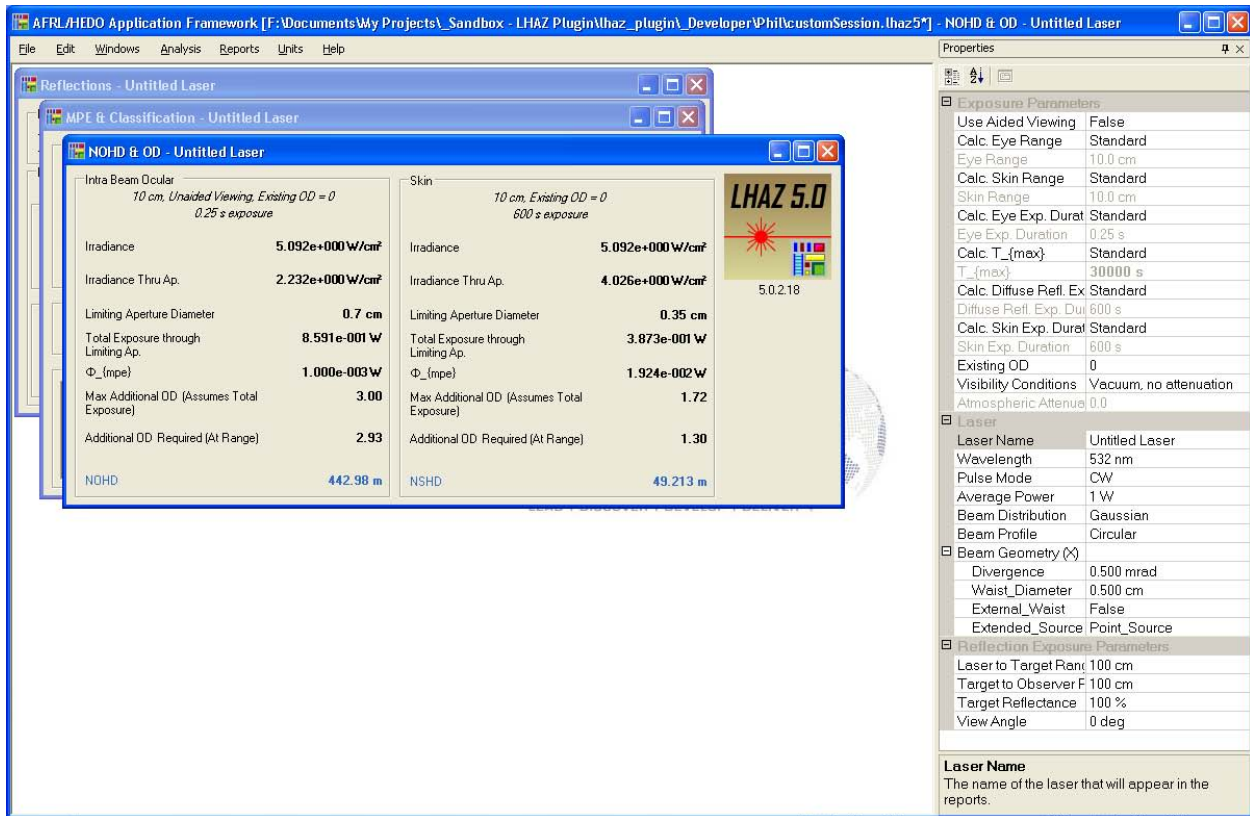
The Framework Windows

The framework application main form consists of a large client area with a menu and property grid. The title bar shows the name of the application, the name of the file that has been loaded or saved along with its modified status (an asterisk '*' denotes that some property has changed since last saved), and which analysis window is active. The Property Grid may be hidden, shown, pinned, and docked with standard windows docking functionality. The size and dock position of the property grid, along with the framework window position and size, the last document loaded, and a list of recent documents are saved in an XML file in the user's system settings folder.

The top menu bar has a variety of menu and sub-menu options. Options that have keyboard shortcuts are listed in the menu. The main window has these menus:

1. The **File** menu group has standard File Loading and Saving Functionality, as well as the ability to quickly load recent documents and Exit the application.
2. The **Edit** menu group contains Undo and Redo functions. These functions will often show what operation is being undone and redone.
3. The **Windows** menu allows the user standard operations on the open analysis windows, like the ability to close, close all, show or hide the properties grid, activate, cascade, tile, switch to next and switch to previous analysis windows.

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4. The **Analysis** menu group is reserved for plug-ins to place their analysis windows. Groups of plug-ins may share a sub-menu, and all of the analysis windows available for those plug-ins may be opened from here.
5. The **Reports** menu allows the user to open and save Rich Text Formatted (RTF) files and edit/save them directly from within the framework. The user may type on these reports and paste values from context menus in the analysis windows. There are also menu options for printing and saving Standard Reports.
6. The **Units** menu group allows the user to select units globally for all of the analysis windows in the application. In LHAZ, for example, the user may change the units that are displayed for all hazard distances, not only for all of the analysis windows in LHAZ, but for any analysis windows in any other loaded plugin that subscribes to the Hazard Distances Global Unit set.
7. The **Help** menu group allows the user to see an "About Window" that shows the date, the version of the framework, and a list of all of the loaded plug-ins. The user may select any plug-in from the list and see the full path filename of the plug-in, the load status, and the version of the plug-in. The load status of LHAZ shows the current version of LTMC. The users may also right-click on any of the text fields in this about window and copy the text to the system clipboard or report.
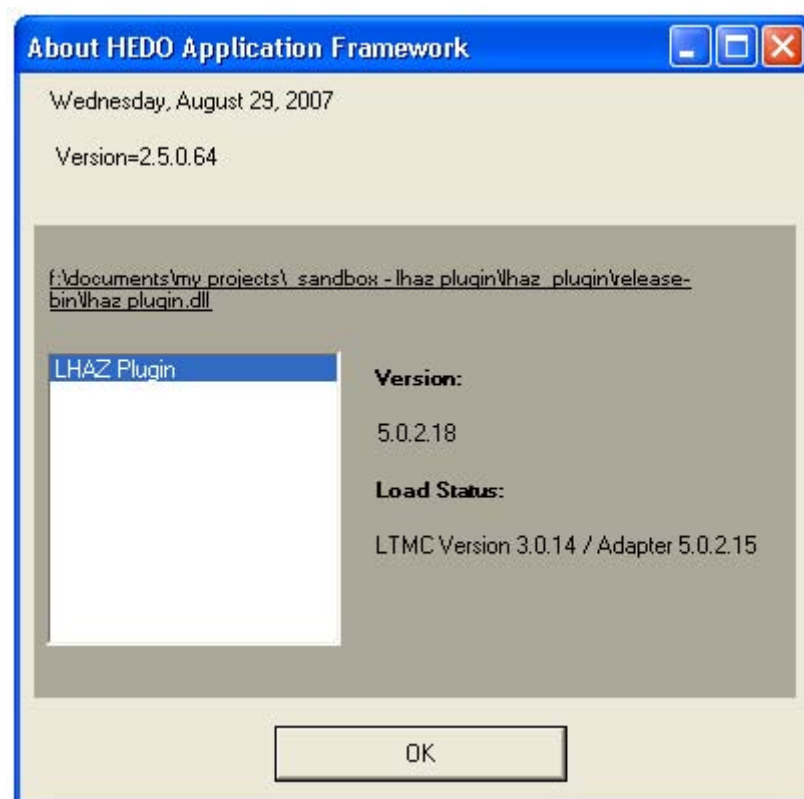
About Window (Plug-ins Found)

3.2.4 Opening Analysis Windows
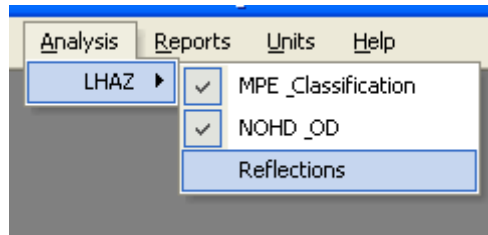
The Analysis Menu is used to open Analysis Windows

As mentioned earlier, analysis windows may be opened from the **Analysis** menu group. An analysis window may only have one instance opened at any one time. The check mark in the menu item shows that the analysis window is already opened. Selecting the menu option for an opened analysis window will activate it and restore the window if it is minimized.

3.2.5 Changing Parameters
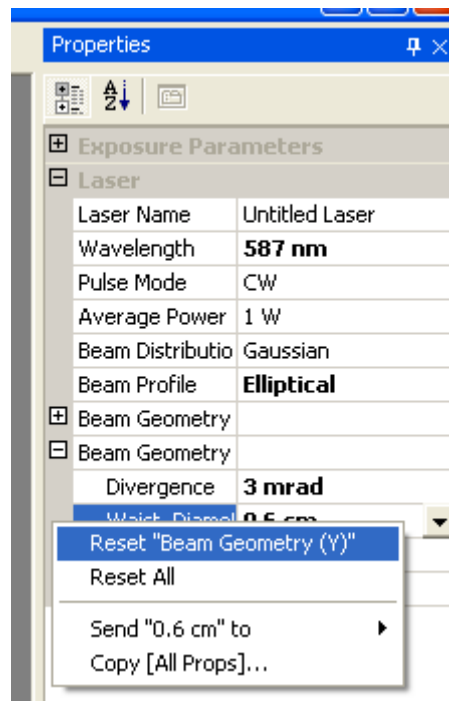
Working with Properties

Analysis windows are places where the user may see the results of the analyses provided by the plug-ins. When an analysis window is active, all of the parameters for the analyses featured in that analysis window are shown as properties in the Property Grid. When the user changes a value in the property grid, the analysis window either automatically updates the analysis results, or provides the user with the ability to re-evaluate the analysis if the analysis takes some time to complete. The user may also use "Ctrl-z" and "Ctrl-y" to undo and redo changes made to properties.

The Property Grid is a robust tool that allows the user to collapse categories and groups of properties. Most properties are just typed into the text fields. Some properties have advanced features that allow drop-down menus or separate dialog windows that allow for editing. Numeric values that have units may often be typed in using those units. If unit entry is allowed, analysts are provided a list of possible conversions in a drop down menu. Properties that represent files provide a standard Window's File Dialog. The descriptions pane of the Property Grid describes the currently selected property in more detail. See the Properties section for more information on working with the Property Grid in general and the LHAZ properties in particular.

The properties in the Property Grid, as well as the groups they are in, provide the user with a right-click context menu that allows the user to reset the value or group of values to a default, or to copy the values to the system clipboard or open report.

3.2.6 Standard Reports
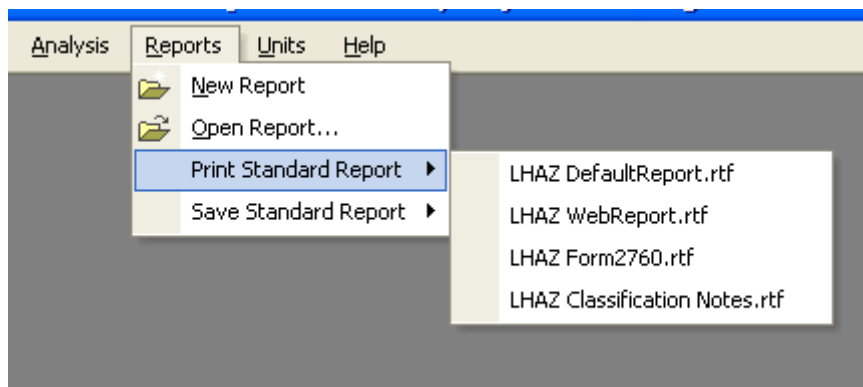
The Standard Reports Menu

As mentioned earlier, the Reports menu allows the user to create a new RTF report within the framework, open an existing report, or print and save standard reports. If the PRINT menu is used, the user is provided with a standard Print Preview Dialog Window of the completed standard report to print from. If the SAVE menu is used, the user is provided with a standard File Save As Dialog Window to save the file. The user may not edit these standard reports directly.

Standard reports are generated when the user selects a report from the "Print Standard Report" or "Save Standard Report" sun-menu. These menus are generated by developers at AFRL/RHDO using macros that extract information from the analysis windows. When a standard report is generated, the analysis windows that are required to generate the report are opened and activated if they are not already opened, so the user may find analysis windows opened that were not opened when they started to generate the report.

3.2.7 User Edited Reporting
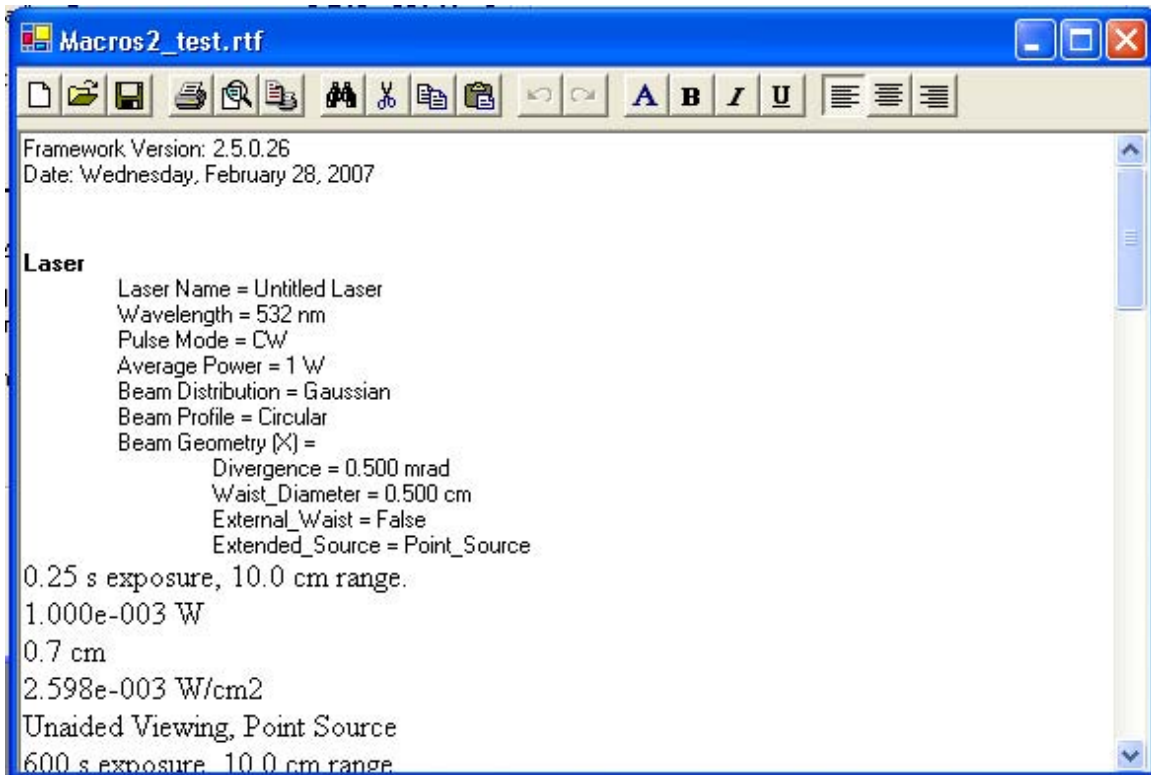
Report Window

The AFRL/RHD Application Framework provides plug-in developers with standard tools that allow users to create reports. The framework provides a rich-text-file editor that allows the user to create their report. Undo/Redo works from within the report windows, as does full featured find/replace and font dialogs.

Many of the labels on the analysis windows, About Window, and Property Grid provide context menus that allow the user to copy the value to the system clip-board, for pasting into applications external to the framework, or to send the value to any open report window. Sending a value to a report window will paste the value at the current cursor position, overwriting any selected text.
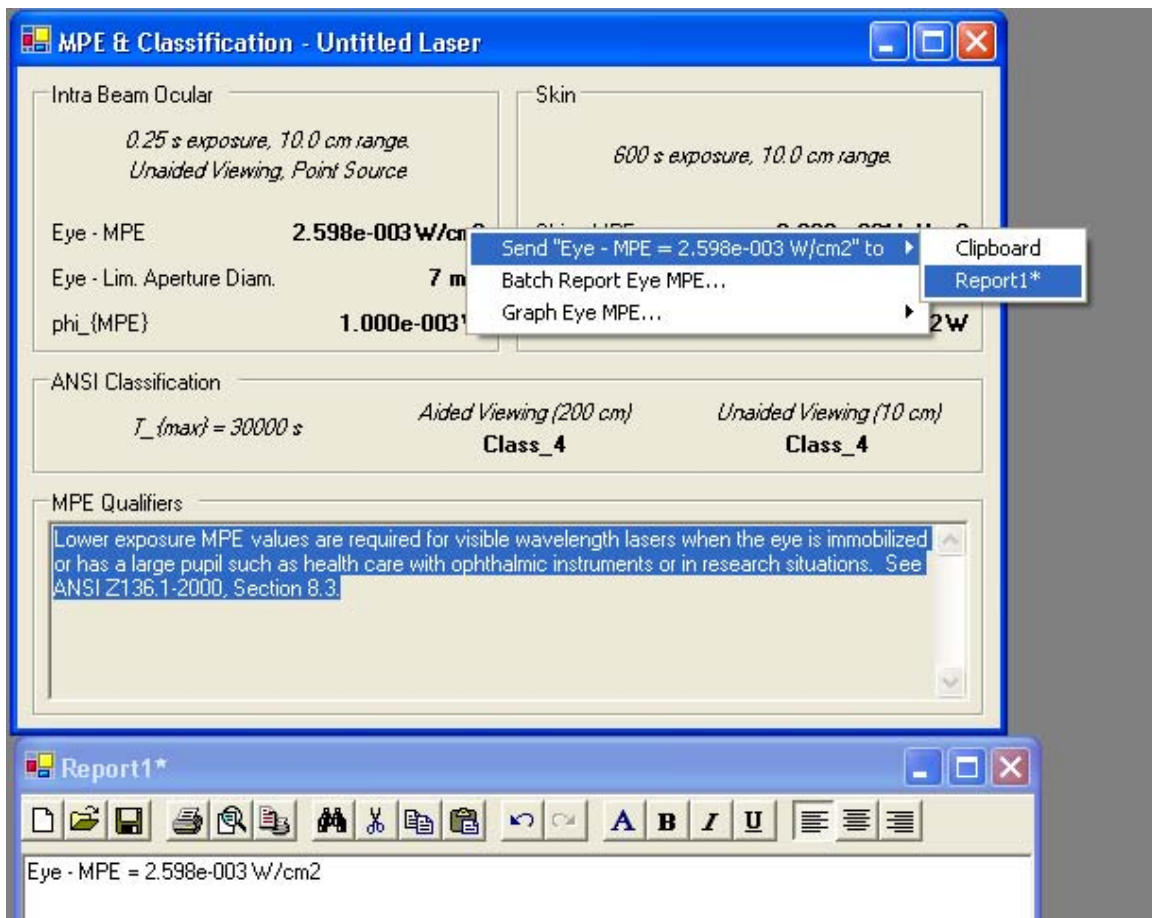
Sending a string to a Report with a Context Menu

The Property Grid also provides the user with a right-click context menu that allows the user to copy values or groups of items to the clipboard. When copying a single item, just that item is immediately placed on the clipboard. If copying a group, a separate window shows the user the block of text to be copied.
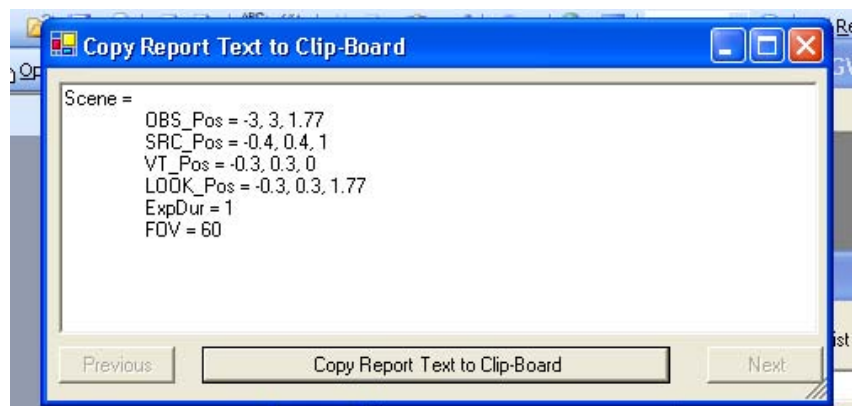
Copying Property Values to the System Clipboard

Analysis windows often also provide context menus for copying single items or blocks of text for analysis results to the clipboard with the same dialog window. The user may select from several versions of the report text to copy to the clipboard.

3.2.8   Graphing
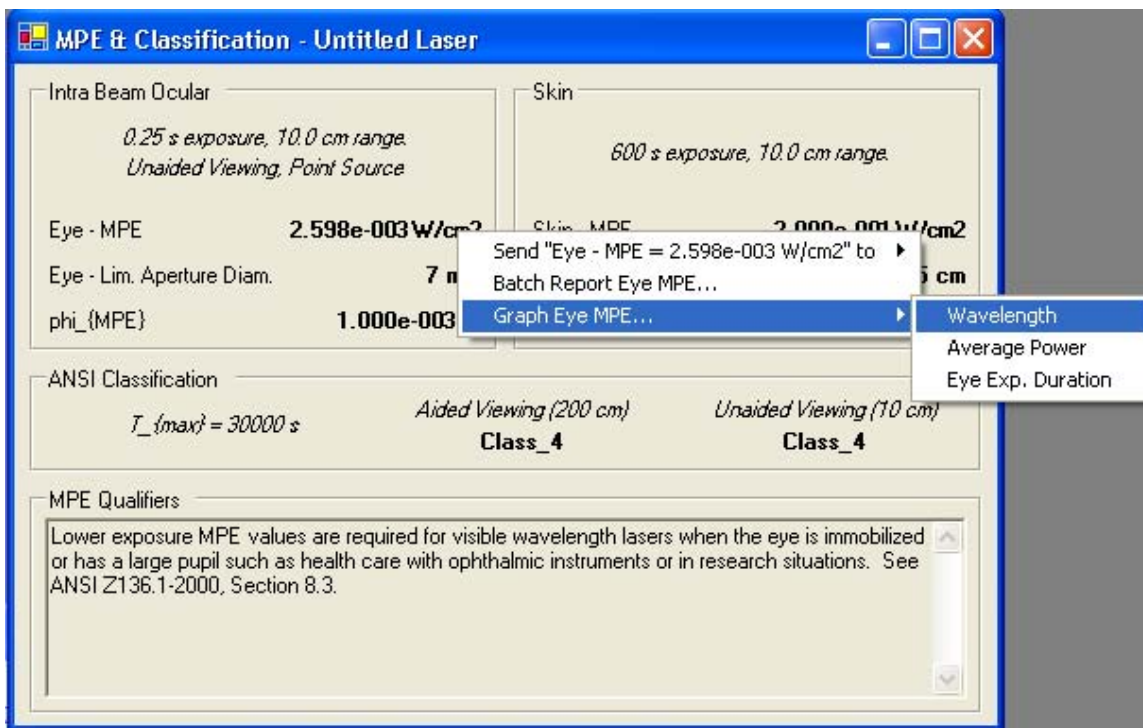
Graph Windows are Accessed via Context Menus

The AFRL/RHD Application Framework provides plug-in developers with standard tools that allow users to create graphs. These graphs are accessed by the user via context menus tied to the GUI widgets that display the results of graph-able analyses. The graphs can be customized for inclusion in any report, either as an image, or the data can be copied and pasted in any spreadsheet application.
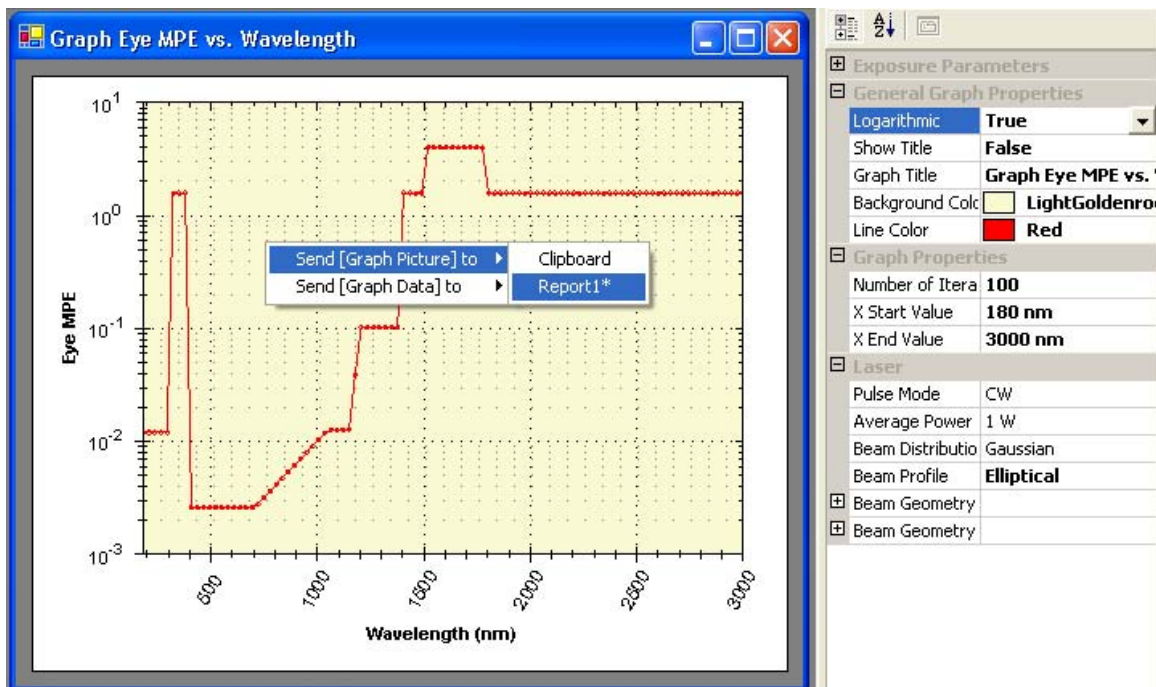
Graph Windows with Properties. Use the Context Menu to send to a Report.

3.2.9   Batch Reporting

The AFRL/RHD Application Framework provides plug-in developers with standard tools that allow users to create batch reports. This feature is also accessed via context menus tied to the user interface fields that display the results of batch reportable analyses. These reports allow the user to perform an analysis over and over again on a set of parameters that can be varied.
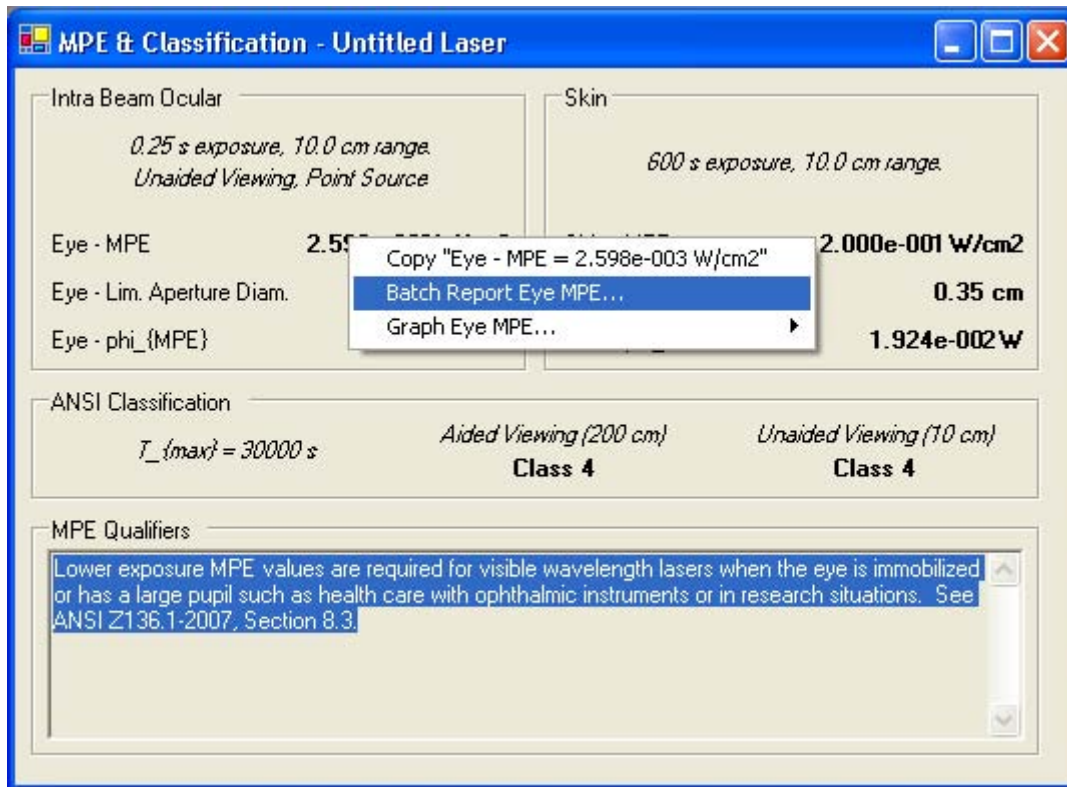
Use the Context Menu to open the Batch Report Window

Batch reporting in the AFRL/RHD Application Framework is performed by the user first generating, then populating, a template file (a .csv file that can be loaded in a spreadsheet program) with the appropriate parameters, then providing that template file to the framework. The framework then generates another .csv file that shows the inputs provided, along with the result of each analysis. The user provides the template file, where to write the output file, and starts generating the report via the Batch Report Window.
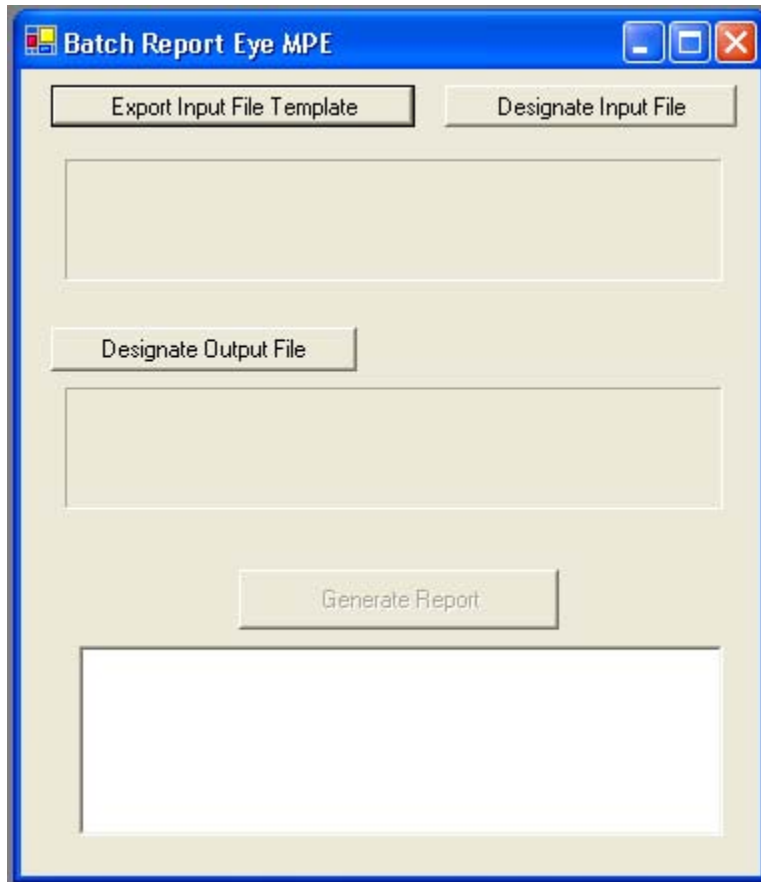
Batch Report Window

The template file needs to be in a specific format. Pressing the "Export Input File Template" button first provides the user with a "File Save…" dialog that prompts the user as to where the newly created template file should be written. It then creates a file that is in the correct format, with a single line that represents the current input parameters and the results. The parameters listed will ONLY be those that are visible and enabled in the property grid when the batch report is run. The user can then use Windows Explorer to navigate to that file and open it. By default, a ".csv" file opens in a spreadsheet program, like MS Excel.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Eye MPE														
2	INPUT													RESULTS	
3	Laser									Exposure Parameters					
4	Wavelengt	Pulse Mod	Average P	Beam Dist	Beam Prof	Beam Geometry (X)				Use Aided	Calc. Ranç	Calc. Eye	Exp. Durati	Eye MPE	
5						Divergence	Waist_Dia	External_V	Extended_Source						
6	532 nm	CW	1 W	Gaussian	Circular	0.500 mrac	0.500 cm	FALSE	Point_Sou	FALSE	Standard	Standard		2.598e-003	W/cm2
7															
8															

Batch Report Template File in MS Excel

Each line of the template file, starting at the first one that has parameters (line 6 in this case), represents a single batch run. The user may edit the file by copying the single example line input parameters to the following lines, and then editing each line to modify the parameters as desired. Leaving a space blank will leave the property without modifying it.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Eye MPE														
2	INPUT													RESULTS	
3	Laser									Exposure Parameters					
4	Wavelengt	Pulse Mod	Average P	Beam Dist	Beam Prof	Beam Geometry (X)				Use Aided	Calc. Rang	Calc. Eye Exp. Durati		Eye MPE	
5						Divergence	Waist_Dia	External_V	Extended_Source						
6	532 nm	CW	1 W	Gaussian	Circular	0.500 mrad	0.500 cm	FALSE	Point_Sou	FALSE	Standard	Standard		2.598e-003 W/cm2	
7	600 nm					0.6 mrad									
8	650 nm					0.7 mrad									
9	700 nm					0.8 mrad									
10	750 nm					0.9 mrad									
11	800 nm					1.0 mrad									
12															

Editing the Input File in MS Excel, modifying the Wavelength and Divergence

In the example shown above, we add five lines (rows 7-11) for a total of six batch runs to be completed, including the original. You can also modify the original parameters if you would like. When the batch report is generated, the results will be over-written. After making the modifications, save the template file.

Back in the Batch Report Window; specify the output file by pressing the "Designate Output File" button. This will prompt you with another "File Save…" dialog that allows you to specify where the final output file will be written. The "Generate Report Window" button will be disabled until both input and output files are specified. Pressing that button generates the report, and opens a window that provides status and error information.
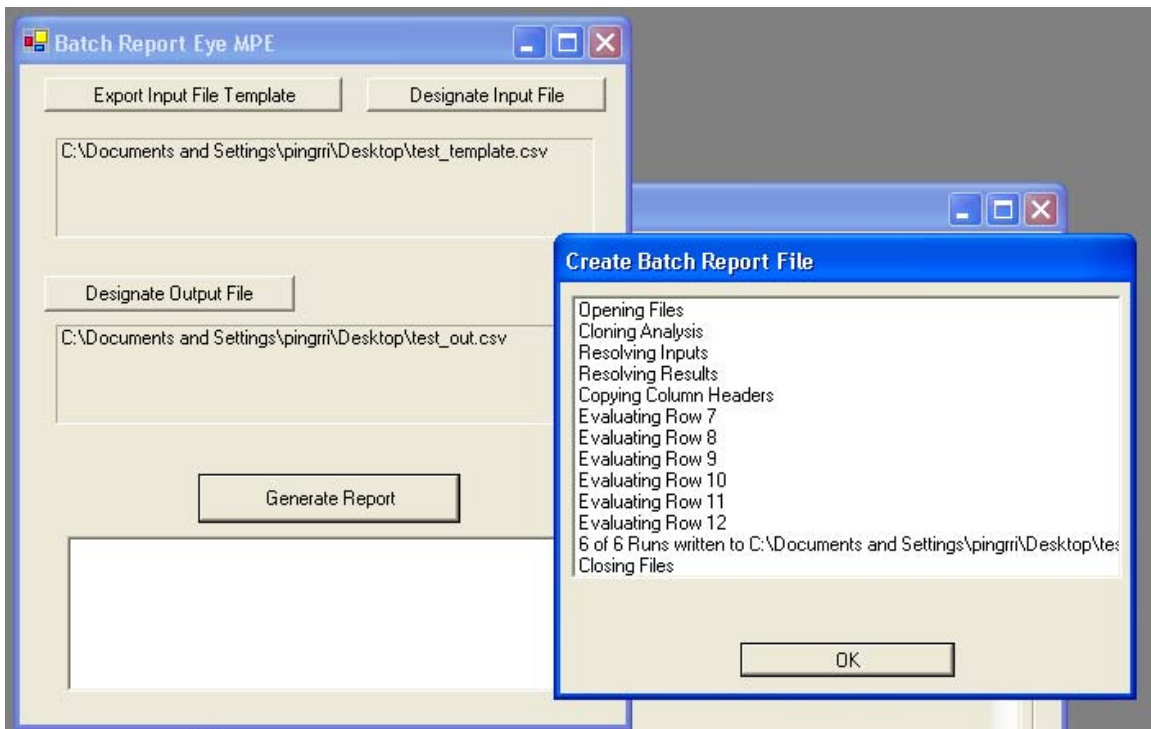
Batch Report Status Window Shows Complete

Dismiss the status window when the report is complete and use Windows Explorer to navigate to the output file and open it. Once again, a ".csv" file opens in a spreadsheet program by default, like MS Excel.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Eye MPE														
2	INPUT													RESULTS	
3	Laser									Exposure Parameters					
4	Wavelengt	Pulse Mod	Average P	Beam Dist	Beam Prof	Beam Geometry (X)		External_V	Extended_Source	Use Aided	Calc. Rang	Calc. Eye Exp. Durati		Eye MPE	
5						Divergence	Waist_Dia								
6	532 nm	CW	1 W	Gaussian	Circular	0.500 mrad	0.500 cm	FALSE	Point_Sou	FALSE	Standard	Standard		2.598e-003 W/cm2	
7	600 nm	CW	1 W	Gaussian	Circular	0.6 mrad	0.500 cm	FALSE	Point_Sou	FALSE	Standard	Standard		2.598e-003 W/cm2	
8	650 nm	CW	1 W	Gaussian	Circular	0.7 mrad	0.500 cm	FALSE	Point_Sou	FALSE	Standard	Standard		2.598e-003 W/cm2	
9	700 nm	CW	1 W	Gaussian	Circular	0.8 mrad	0.500 cm	FALSE	Point_Sou	FALSE	Standard	Standard		2.546e-003 W/cm2	
10	750 nm	CW	1 W	Gaussian	Circular	0.9 mrad	0.500 cm	FALSE	Point_Sou	FALSE	Standard	Standard		3.205e-003 W/cm2	
11	800 nm	CW	1 W	Gaussian	Circular	1.0 mrad	0.500 cm	FALSE	Point_Sou	FALSE	Standard	Standard		4.034e-003 W/cm2	
12															

Output File Results

The output file shows the results of each of the analyses in order. Note that each row shows the parameters that the user provided, and reminds the user of the other parameters that were not changed as well.

3.2.10 User Selected Units

Locally Defined Units via Context Menu

The user may also use the context menu to select units for many of the analysis results in the analysis windows. These context menus resemble those used in the property grid. The user may also use the "Units" top-level menu to select units which would affect all of the analyses of a particular type, rather than just that specific item. All of these unit settings are persisted for the next framework session.

3.2.11 Saving Your Work

The File menu group allows for standard document loading and saving. When the framework launches, it attempts to load that last used file. If that file no longer exists on the user's system, a dialog box will inform the user of the failed attempt to load. A list of the most recently used files is listed in the File menu group as well. The title bar shows the file name of the currently opened document, along with an asterisk '*' when the current document is modified from its original saved state.

The document saved by the framework has the extension ".afs". The document is in an XML text format that can be edited (carefully) in any text editor. The document contains the values of all of the properties for all loaded plug-ins in the framework. It also contains the positions and sizes of all of the opened analysis windows, as well as which one is active. The framework is robust in handling differences in the loaded plug-ins and versions from the time the file is saved to the time the file is opened. This means that a user may send a file to a colleague even if both users do not have the same set of plug-ins.

3.3   INSTALLING LHAZ VERSION 5

If you're installing LHAZ from CD (and the "autorun" capability is turned on), you should simply have to follow the on-screen instructions to install LHAZ. If you have downloaded LHAZ, you will need to open the Setup.exe file (usually by double-clicking it), and then follow the on-screen instructions.

3.4   REMOVING LHAZ VERSION 5

LHAZ can be removed from your system by looking under the "Add/Remove Programs" option in the Windows Control Panel

3.5   UPDATING LHAZ VERSION 5

LHAZ 5 is maintained by the Air Force Research Laboratory, Optical Radiation Branch at Brooks City-Base, TX. Updates are occasionally available to the software, as well as this user guide. Information regarding the latest version of LHAZ can be obtained by contacting the Optical Radiation Branch. (See Appendix F for contact information.)

Note that for some Microsoft ™ operating systems, administrator privileges may be required to install LHAZ 5 in the default location. Administrator privileges are not required by LHAZ 5 itself.

3.6 FREQUENTLY ASKED QUESTIONS AND TROUBLESHOOTING TIPS

1) **Q: My LHAZ 5 installation CD does not start the install process automatically when I insert the CD. How can I get LHAZ 5 to install?**

   A: Open your Windows Explorer and right-click on the icon for the CDROM drive. Select "Explore" and find the "Setup.exe" file. Double-click the setup.exe file, and the installation process should begin.

2) **Q: How do I remove LHAZ 5 from my computer?**

   A: From the Windows Start Menu, select Settings, Control Panel. Double-Click the "Add/Remove Programs" Icon. In the list of programs installed, there should be an LHAZ 5. Remove the program by selecting the appropriate removal option for the version of Windows that you currently have installed.

3) **Q: I cannot view the User's Guide on the CD, or/and I cannot view the User's Guide from the LHAZ group in the Start Menu. What is wrong?**

   A: You must have either Microsoft Word or Adobe Acrobat Reader Installed on your computer in order to view the User's Guide. You can download the Adobe Acrobat Reader from the internet at: http://www.adobe.com/.

4) **Q: Can I give LHAZ 5 to someone else to install on his or her computer? Can I make copies of the LHAZ 5 CD?**

   A: No. Please direct anyone interested in obtaining LHAZ 5 to AFRL/RHDO. The distribution is limited to DOD employees and DOD contractors. We keep a record of the number of installations throughout the DOD and keep a record of user information so that they can be notified of any changes or updates to LHAZ. Accurate records of the number of installations are also critical to our ability to continue providing future versions of LHAZ.

5) **Q: Where can I get support or information regarding updates to LHAZ 5?**

   A: LHAZ 5 is maintained by the Air Force Research Laboratory, Optical Radiation Branch at Brooks City-Base, TX. Updates are occasionally available to the software, as well as the Users Guide. Information regarding the latest version of LHAZ can be found by contacting them (see Appendix F). Users can request an updated version of LHAZ or the latest user's manual.

6) **Q: Where can I register my copy of LHAZ 5?**

    A: When you receive and install LHAZ 5, please take the time to **register** the software with the Air Force Research Laboratory, Optical Radiation Branch at Brooks City-Base, TX.   See Appendix F for contact information. This will allow us to notify you if there are any updates, and contact you when the next version of LHAZ is released. **Note that you will not receive updates if you have not registered your software**.

    It is very important for AFRL/RHDO to accurately track the number of LHAZ installations DOD-wide, so that continued funding for this important project will continue.

7) **Q: Can I view the LHAZ 5 User's Guide without installing the software?**

    A: Yes, an Adobe Acrobat version of the User's Guide is included on the LHAZ 5 distribution CD in the top-level directory. Adobe Acrobat Reader™ is required to view the document.

8) **Q: How can I determine what version/release of LHAZ I have installed?   What is the LTMC version number? What should I do if there is an update available?**

    A: The framework's "Help", "About AFRL/RHD Application Framework…" pull-down menu will open a dialog box that will give the current version of the AFRL/RHD Application Framework and each of the plug-ins that are currently installed. Select "LHAZ Plugin" from the list of installed plug-ins (it may be the only one) to see the version, release, and build number of LHAZ and LTMC. The version of LHAZ should be 5.0.#.#, where the "#" represents some numeric value. Also shown will be an LTMC version number, most likely 3.#.#. The LTMC library is used by LHAZ to perform hazard calculations. It is basically the "smarts" behind LHAZ and is used in many AFRL/RHDO laser applications; as a consequence, it may be updated occasionally to include additional features that will not affect LHAZ.

    AFRL/RHDO may update the distribution CD and this will be given a "Release Number". A given Release Number will have changes to the content of the distribution CD, and may include updated versions of LHAZ or LTMC. For details on any updates, contact the Optical Radiation Branch by telephone, e-mail, or their web site. See Appendix F for contact information.

4. CHANGE NOTES

LHAZ has evolved through several iterations to provide more features and accurate analyses to our users. The early versions of LHAZ 3 were written as a DOS console application. LHAZ 4 was written as a tabbed windows application. This newest incarnation of LHAZ is written as a plug-in to the AFRL/RHD Application Framework.

4.1 SYNOPSIS OF CHANGES FROM LHAZ V4.4 TO V5.0

This newest version of LHAZ is a complete reengineering of the LHAZ application. It implements the new American National Standard for Safe Use of Lasers (ANSI Z136.1-2007) [1]. It also incorporates the AFRL/RHD Application Framework, leveraging the Framework to provide a common, powerful user interface for multiple analyses. The design of LHAZ 5 is meant to aid the user in seeing more analyses at one time, and is more robust, allowing additional analyses or parameters.

Changes between earlier versions of LHAZ are listed in Appendix G.

5.   PROPERTIES AND ANALYSIS WINDOWS

There are three Analysis Windows that can be opened in LHAZ. These can all be accessed via the menu "Analysis → LHAZ". These three analysis windows correspond to the three tabbed analysis panes of LHAZ 4 of the same name. Each of these windows shows the results of various analyses. As with any plugin for the Application Framework, making an analysis window active will cause all of the properties relevant that window's analyses to be shown in the Property Grid. This design allows for each analysis window to take up less screen real estate than before. This means that more can be shown on the analysis window, and also that multiple analysis windows can be placed on the framework's "desktop". The analysis windows often share some of the same properties, like the laser parameters. This means that the user can see the effects of changes to a specific parameter across multiple analysis windows. There may even be plug-ins in the future that share properties.
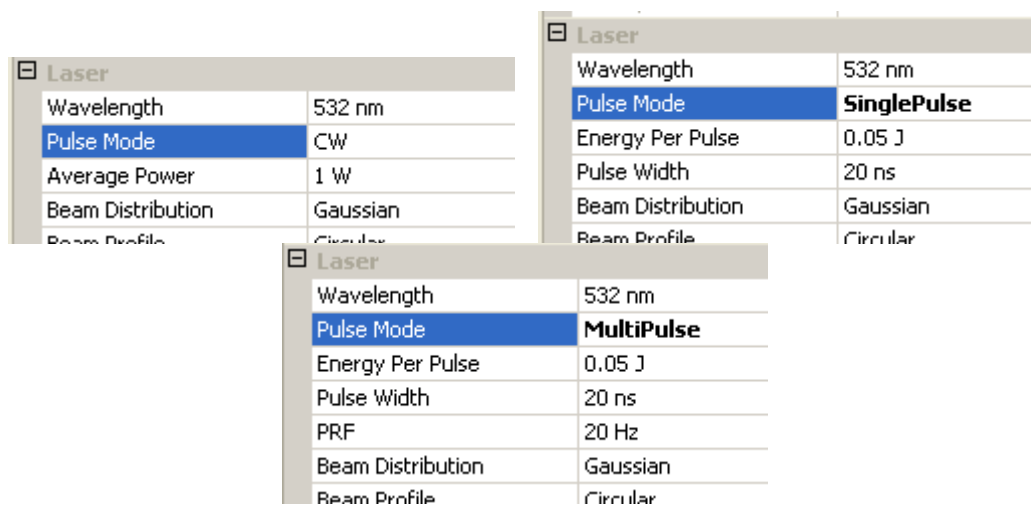
5.1   PROPERTIES

5.1.1   General Property Notes

Properties are organized into categories in the properties grid, which can each be expanded. These categories are:

- Exposure Parameters
- Laser
- Reflection Exposure Parameters (Only for the Reflections Analysis Window)

There are times when some properties are hidden because they are not applicable, due to the value of some other property. One example would be that the "Energy per Pulse" property is not visible when the user has chosen "CW" (for continuous wave) for the "Pulse Mode" property.

Different properties showing based on the value of "Pulse Mode"

Some properties have sub-properties and can be expanded. These properties will show the standard '+' or '-' to expand or collapse the property.
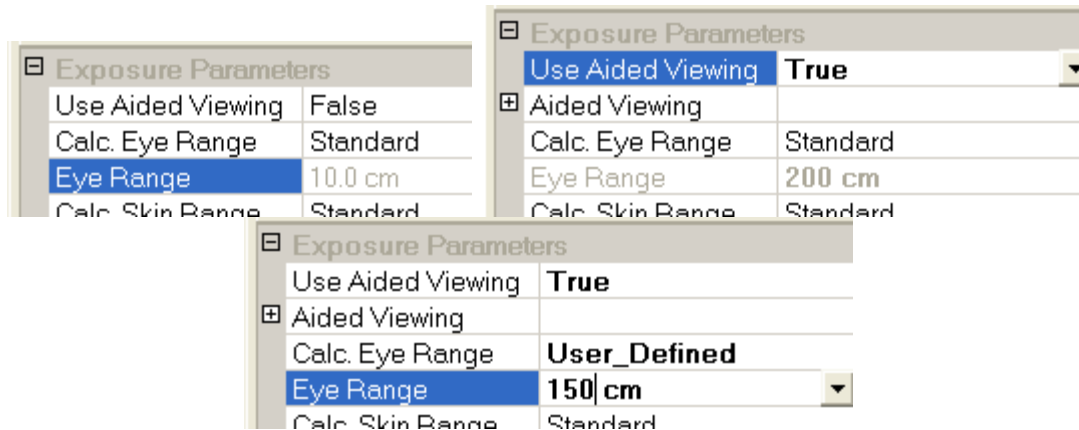
Using the Standard ANSI Defined Range or the User Defined Range

The ANSI standard[1] recommends values for many of the properties based on the values of other properties (like wavelength or the existence of aided viewing). For properties where there is an ANSI[1] recommendation, there is typically another property just above it that allows the user to choose between "Standard" and "User_Defined". The default, Standard, will cause the actual property to be grayed out. The property will always be updated to reflect the ANSI standard[1] recommended value based on the other properties. If "User_Defined" is selected, the corresponding property will be enabled, allowing the user to edit the value.
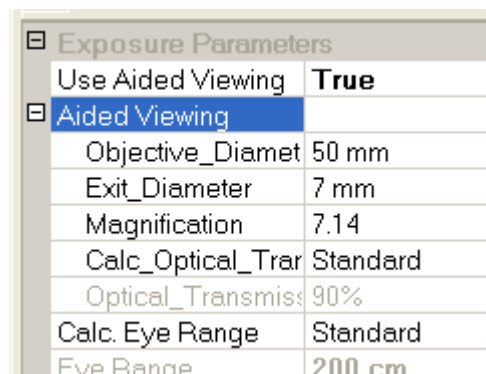
The "Aided Viewing" parameters are sub-properties.

The "Optical_Transmissivity" uses the ANSI standard default.

Some properties, like "Optical_Transmissivity", may be entered as a percentage, like "90%", or as a multiplier value, like "0.90". Many of the properties may be entered in units that relate to the property. For these kinds of properties, a drop-down window on the property provides the available conversions, or the user can type the value with the units. If a value is typed without units, the current units are assumed.
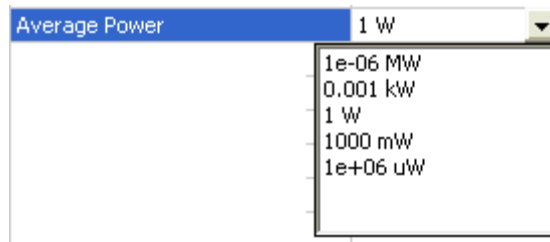
Available Units for "Average Power"

Standard prefixes for the various units can be assumed:

Prefix	Units	Magnitude
f	femto-	10^{-15}
p	pico-	10^{-12}
n	nano-	10^{-9}
u	micro-	10^{-6}
m	milli-	10^{-3}
c	centi-	10^{-2}
k	kilo-	10^{3}
M	mega-	10^{6}

__EXAMPLE:__ Your laser has a pulse width of 20 x 10^{-9} s. You could enter this value in many different ways, and LHAZ would still recognize it. You could enter "20 ns", or "0.02 us". LHAZ also recognizes scientific and engineering notations, such as "20e-9", "20E-09", or "2.0E-8". Distance and length fields are treated in a similar manner; "km" refers to kilometers, "mm" refers to millimeters, etc. Other examples include kilohertz ("kHz"), milliseconds ("ms"), nanometers ("nm"), and micrometers ("um"). Note that you cannot place a comma in a number entry field.

The following sections list all of the properties to be found in LHAZ, along with which category they belong to, description, valid ranges, default values, and how the properties depend on each other.

5.1.2 Laser Properties

Laser	
Laser Name	Untitled Laser
Wavelength	532 nm
Pulse Mode	**MultiPulse**
Average Power (Pulsed)	1 W
Energy Per Pulse	0.05 J
Pulse Width	20 ns
PRF	20 Hz
Beam Distribution	Gaussian
Beam Profile	**Elliptical**
⊟ Beam Geometry (X)	
Divergence	0.500 mrad
Waist_Diameter	0.500 cm
External_Waist	False
Extended_Source	**Const_Angle**
ExtSrc_Angle	0.0 mrad
ExtSrc_AperDiam	0.0 cm
⊟ Beam Geometry (Y)	
Divergence	0.500 mrad
Waist_Diameter	0.500 cm
External_Waist	False
Extended_Source	**Const_Diam**
ExtSrc_AperDiam	0.0 cm

Laser Properties

Laser Name

Category:	Laser
Type & Units:	String
Default Value:	"Untitled Laser"
Range & Exceptions:	Must not be empty
Dependencies:	none
Description:	The name of the laser that will appear in the reports.

Wavelength

Category:	Laser
Type & Units:	Wavelength (um, nm, pm, fm)
Default Value:	532 nm
Range & Exceptions:	[0.180 um, 1000 um]
Dependencies:	none
Description:	The wavelength of the laser, [0.180 um – 1000 um]. The laser

wavelength is critical to the correct computation of maximum permissible exposure values. Also, many recommended default values provided by LHAZ are based upon the wavelength of the laser. Any time that the user changes the laser wavelength, the recommended values, such as exposure times, will be updated.

Pulse Mode

Category:	Laser
Type & Units:	Enumeration: CW, SinglePulse, MultiPulse
Default Value:	CW
Range & Exceptions:	-
Dependencies:	none
Description:	The type of output the laser produces. The Continuous Wave (CW) option is for a laser that has a constant output power. The SinglePulse option is for lasers that emit single bursts of energy shorter than 0.25-seconds in duration. The MultiPulse option is used when the laser emits regularly repeating pulses of energy, which have constant pulse duration and a constant spacing between pulses.

Average Power

Category:	Laser
Type & Units:	Power (MW, kW, W, mW, uW)
Default Value:	1.0 W
Range & Exceptions:	> 0
Dependencies:	Only enabled when Pulse Mode is CW. For pulsed lasers, the average power shows as the average power in watts. For multiple pulse lasers, the
Description:	The average power of a CW laser. OR The average power of a pulsed laser. The energy per pulse times the PRF of a multi-pulse laser, or the energy per pulse divided by the pulse width for a single-pulse laser.

Energy Per Pulse

Category:	Laser
Type & Units:	Energy (MJ, kJ, J, mJ, uJ)
Default Value:	0.05 J
Range & Exceptions:	> 0
Dependencies:	Only visible when Pulse Mode is not CW
Description:	Total energy provided in a single pulse of a pulsed laser.

Pulse Width

Category:	Laser
Type & Units:	Time (s, ms, us, ns, ps, fs)
Default Value:	20 ns
Range & Exceptions:	> 0, < 1 / PRF for MultiPulse
Dependencies:	Only visible when Pulse Mode is not CW
Description:	The length of time a single pulse is delivered. Pulse width must be less than 1/PRF for a multiple pulse laser.

PRF

Category:	Laser
Type & Units:	Hertz (Hz, KHz, MHz)
Default Value:	20 Hz
Range & Exceptions:	< 1/ PulseWidth
Dependencies:	Only visible when Pulse Mode is MultiPulse
Description:	Pulse Repetition Frequency, the rate pulses are delivered for a multiple pulse laser. PRF must be less than 1/Pulse Width

Beam Distribution

Category:	Laser
Type & Units:	Enumeration: Gaussian, TopHat
Default Value:	Gaussian
Range & Exceptions:	**-**
Dependencies:	Disabled on TopHat when BeamProfile is Rectangular
Description:	Beam Distribution must be TopHat if the Beam Profile is Rectangular.

For the Gaussian distribution, the beam geometry parameters of beam waist diameter and beam divergence must be specified at the 1/e point of intensity. In the Top-Hat distribution, the beam diameter is the width of the beam at the 50% intensity points.

Beam Profile

Category:	Laser
Type & Units:	Enumeration: Circular, Elliptical, Rectangular
Default Value:	Circular
Range & Exceptions:	
Dependencies:	none
Description:	The profile shape of the beam. If the shape is rectangular, Beam Distribution must be TopHat.

The options currently supported default to circular beam, which is the most commonly applied model for beam shape. The two new options provided by LHAZ include the elliptical beam shape and the rectangular beam shape. In these two beam shapes, the user must enter values for the beam geometry both along an X and a Y-axis. Note that the Rectangular beam profile cannot be selected for the Gaussian distribution.

Beam Geometry

Category:	Laser
Type & Units:	LaserGeometry CLASS, See Below for Members
Default Value:	-
Range & Exceptions:	-
Dependencies:	If the BeamProfile is circular, there is only one of these, that affects both axes, and the Name is "Beam Geometry (X)". If the BeamProfile is not circular, there will be two of these, one for primary axis and one for secondary axis.
Description:	The geometry of the beam along the primary axis or both axes if circular. **OR** The geometry of the beam along the secondary axis.

Beam Geometry. Divergence

Category:	Laser
Type & Units:	Angle (deg, rad, mrad, urad, nrad)
Default Value:	0.500 mrad
Range & Exceptions:	> 0
Dependencies:	none
Description:	The angular divergence of the beam along this axis at 1/e power points for a gaussian beam, or at 50% intensity points for a top-hat beam.

Beam Geometry.Waist_Diameter

Category:	Laser
Type & Units:	Length (mm, cm, in, ft, yd, m)
Default Value:	0.500 cm
Range & Exceptions:	> 0
Dependencies:	none
Description:	The minimum diameter of the beam at the waist, or when it is the most focused at 1/e power points for a gaussian beam, or at 50% intensity points for a top-hat beam.

Beam Geometry.External_Waist

Category:	Laser
Type & Units:	boolean
Default Value:	false
Range & Exceptions:	-
Dependencies:	none
Description:	Set this to true for a laser that converges outside of the aperture.

Laser.Beam Geometry.Waist_Distance

Category:	Laser
Type & Units:	Length (mm, cm, in, ft, yd, m)
Default Value:	0 cm
Range & Exceptions:	-
Dependencies:	only visible when External_Waist is true
Description:	Distance from the aperture to where the beam is most focused. Use a negative number if the waist is inside of the laser cavity.

Beam Geometry.Extended_Source

Category:	Laser
Type & Units:	Enumeration: Point_Source, Const_Diam, Const_Angle
Default Value:	Point_Source
Range & Exceptions:	-
Dependencies:	none
Description:	Does this axis of the laser create an extended source on the retina?

Beam Geometry.ExtSrc_Angle

Category:	Laser
Type & Units:	Angle (deg, rad, mrad, urad, nrad)
Default Value:	0.0 mrad
Range & Exceptions:	>= 0
Dependencies:	Only visible when ExtendedSrc is Const_Angle
Description:	Special optics causes a constant angle extended source on the retina at close ranges.

Beam Geometry.ExtSrc_AperDiam

Category:	Laser
Type & Units:	Length (mm, cm, in, ft, yd, m)
Default Value:	0.0 cm
Range & Exceptions:	>= 0
Dependencies:	Only visible when ExtendedSrc is NOT Point_Source
Description:	The diameter of the aperture used to determine extended sources. If a constant angle is specified, this diameter is used at range.

5.1.3   Exposure Parameters

Exposure Parameters

Use Aided Viewing

Category:	Exposure Parameters
Type & Units:	bool
Default Value:	false
Range & Exceptions:	
Dependencies:	none
Description:	Select true to provide aided viewing parameters.

When the aided viewing parameters are not being used, LHAZ assumes a transmittance of 1.0 and that the laser energy is being collected by the applicable ocular limiting aperture from the MPE and Classification page for the corresponding exposure time.

Aided Viewing

Category:	Exposure Parameters
Type & Units:	AidedViewing
Default Value:	
Range & Exceptions:	
Dependencies:	Not browsable if UseAidedViewing is false
Description:	Parameters for aided viewing conditions.

Aided Viewing.Objective_Diameter

Category:	Exposure Parameters
Type & Units:	Length (mm, cm, in, ft, yd, m)
Default Value:	50 mm
Range & Exceptions:	> ExitDiam
Dependencies:	none
Description:	The objective aperture for aided viewing.

Aided Viewing.Exit Diam.

Category:	Exposure Parameters
Type & Units:	Length (mm, cm, in, ft, yd, m)
Default Value:	7 mm
Range & Exceptions:	> 0, < ObjDiam
Dependencies:	none
Description:	The exit aperture for aided viewing.

Aided Viewing.Gain

Category:	Exposure Parameters
Type & Units:	percentage or decimal
Default Value:	714.00 % *(auto calculated Do / De)*
Range & Exceptions:	> 1.0, < Do / De
Dependencies:	none
Description:	The magnification factor of the optics. Must not be less than one or greater than objective diameter / exit diameter. Gain is automatically re-calculated whenever the exit or objective diameters change.

Aided Viewing.Calc_Optical_Transmissivity

Category:	Exposure Parameters
Type & Units:	Enumeration: Standard, User_Defined
Default Value:	Standard
Range & Exceptions:	
Dependencies:	none
Description:	Use the standard optical transmittance based on wavelength, or provide a user defined value.

Aided Viewing.Optical_Transmissivity

Category:	Exposure Parameters
Type & Units:	percentage or decimal
Default Value:	90% (calculated based on wavelength)
Range & Exceptions:	> 0%, <= 100%
Dependencies:	Disabled and automatically calculated if CalcOpticalTrans is Standard.
Description:	The transmissivity of the optics based on wavelength. Calculated

automatically based on wavelength, or set Calc_Optical_Transmissivity to User_Defined to set manually.

Calc. Eye Range

Category:	Exposure Parameters
Type & Units:	Enumeration: Standard, User_Defined
Default Value:	Standard
Range & Exceptions:	
Dependencies:	none
Description:	Use the standard range for analyses for this laser, or provide a user

defined value.

Eye Range

Category:	Exposure Parameters
Type & Units:	Distance (mm, cm, in, ft, yd, m)
Default Value:	10.0 cm (calculated based on wavelength and aided viewing)
Range & Exceptions:	> 0
Dependencies:	Disabled and automatically calculated if CalcRange is Standard.
Description:	The distance between the laser aperture and the viewer. The standard

range is typically 10 cm for non-aided viewing and 200 cm for aided viewing OR if there is an external beam waist, the distance might be at the laser's focal point. Aided viewing optics and atmospheric effects may come into play when computing the distance at which the most energy enters the limiting aperture.

This value is important for some UV and IR wavelength values for which the MPE can be a function of laser beam diameter, and consequently a function of distance from the laser.

Calc. Skin Range

Category:	Exposure Parameters
Type & Units:	Enumeration: Standard, User_Defined
Default Value:	Standard
Range & Exceptions:	
Dependencies:	none
Description:	Use the standard range for analyses for this laser when dealing with

skin exposures, or provide a user defined value.

Skin Range

Category:	Exposure Parameters
Type & Units:	Distance (mm, cm, in, ft, yd, m)
Default Value:	10.0 cm (calculated based on wavelength)
Range & Exceptions:	> 0
Dependencies:	Disabled and automatically calculated if CalcSkinRange is Standard.
Description:	The distance between the laser aperture and the observer. The standard

range is 10 cm OR if there is an external beam waist, the distance might be at the laser's focal point. Atmospheric effects may come into play when computing the distance at which the most energy enters the skin limiting aperture.

Calc. Eye Exp. Duration

Category:	Exposure Parameters
Type & Units:	Enumeration: Standard, User_Defined
Default Value:	Standard
Range & Exceptions:	
Dependencies:	none
Description:	Sets the ocular exposure duration for the standard ANSI[1] defined value

for accidental exposures, or allows a user-defined exposure duration.

Eye Exp. Duration

Category:	Exposure Parameters
Type & Units:	Time (s, ms, us, ns, ps, fs)
Default Value:	0.250 s (calculated based on wavelength)
Range & Exceptions:	>= minimum, <= 30,000 or Single Pulse Pulse Width.
Dependencies:	Disabled and automatically calculated if not User_Defined
Description:	The exposure duration used for all ocular calculations. The value is

limited to no more than 30,000 seconds, or the pulse width of a single-pulse laser. The minimum exposure duration is dictated by the shortest exposure duration for which an MPE is defined for the laser's wavelength.

Calc. T_{max}

Category:	Exposure Parameters
Type & Units:	Enumeration: Standard, User_Defined
Default Value:	Standard
Range & Exceptions:	
Dependencies:	none
Description:	Sets the exposure duration for classification as the standard ANSI[1]

defined value for T_{max}, or allows a user-defined exposure duration.

T_{max}

Category:	Exposure Parameters
Type & Units:	Time (s, ms, us, ns, ps, fs)
Default Value:	30,000 s (calculated based on wavelength)
Range & Exceptions:	>= minimum, <= 30,000 or Single Pulse Pulse Width.
Dependencies:	Disabled and automatically calculated if not User_Defined
Description:	The exposure duration used for classification. The value is limited to

no more than 30,000 seconds, or the pulse width of a single-pulse laser. The minimum exposure duration is dictated by the shortest exposure duration for which an MPE is defined for the laser's wavelength.

Calc. Diffuse Refl. Exp. Duration

Category:	Exposure Parameters
Type & Units:	Enumeration: Standard, User_Defined
Default Value:	Standard
Range & Exceptions:	
Dependencies:	none
Description:	Sets the diffuse reflection exposure duration for the standard ANSI[1]

defined value for accidental exposures, or allows a user-defined exposure duration.

Diffuse Refl. Exp. Duration

Category:	Exposure Parameters
Type & Units:	Time (s, ms, us, ns, ps, fs)
Default Value:	600 s (calculated based on wavelength)
Range & Exceptions:	>= minimum, <= 30,000 or Single Pulse Pulse Width.
Dependencies:	Disabled and automatically calculated if not User_Defined
Test Results:	
Description:	The exposure duration used for all diffuse reflection exposure

calculations. The value is limited to no more than 30,000 seconds, or the pulse width of a single-pulse laser. The minimum exposure duration is dictated by the shortest exposure duration for which an MPE is defined for the laser's wavelength.

Calc. Skin Exp. Duration

Category:	Exposure Parameters
Type & Units:	Enumeration: Standard, User_Defined
Default Value:	Standard
Range & Exceptions:	
Dependencies:	none
Description:	Sets the skin and diffuse exposure duration for the ANSI[1] defined

accidental value, or allows a user-defined exposure duration.

Skin Exp. Duration

Category:	Exposure Parameters
Type & Units:	Time (s, ms, us, ns, ps, fs)
Default Value:	600 s (calculated based on wavelength)
Range & Exceptions:	>= minimum, <= 30,000 or Single Pulse Pulse Width.
Dependencies:	Disabled and automatically calculated if not User_Defined
Description:	The exposure duration used for all skin and diffuse reflection

calculations. The value is limited to no more than 30,000 seconds, or the pulse width of a single-pulse laser. The minimum exposure duration is dictated by the shortest exposure duration for which an MPE is defined for the laser's wavelength.

Existing OD

Category:	Exposure Parameters
Type & Units:	Numeric
Default Value:	0
Range & Exceptions:	>= 0
Dependencies:	none
Description:	The attenuating optical density that is already being used.

The OD specifies on a logarithmic scale the amount that the laser power or energy is reduced. For example, a laser operator may be wearing LEP with an OD of 3.0 at the wavelength of the laser. This LEP is reducing the potential exposure to the laser by a factor of 1,000. LHAZ will compute the NOHD and (additional) OD requirements for the exposure conditions supplied.

Visibility Conditions

Category:	Exposure Parameters
Type & Units:	String Enumeration:

Vacuum, Mil. Std. Grnd-Grnd, Exceptionally Clear(100 km), Very Clear(50 km), Clear(20 km), Light Haze(10 km), Haze(4 km), Thin Fog(2 km), Light Fog(1 km), Moderate Fog(0.5 km), User Defined

Default Value:	Vacuum, no attenuation
Range & Exceptions:	
Dependencies:	none
Description:	The visibility conditions at 100 km. An option also exists for user

defined attenuation and military standard for visible ground to ground scenarios.

Atmospheric attenuation can also be specified. The reduction of laser exposure at long distances can be significant even when visibility is good. LHAZ is limited to constant atmospheric attenuation coefficient, which exponentially reduces exposure as a function of distance. More advanced models may be required for high-energy lasers which are directed above the atmosphere. The user may select the *Visibility Conditions* from a pull-down menu, and the recommended atmospheric attenuation will be computed based upon the visibility and the wavelength of the laser. If this value is not appropriate in the opinion of the LSO, the value may be over-ridden by using the "User Defined" option and typing in the desired attenuation coefficient in the *Atmospheric Attenuation* property.

Atmospheric Attenuation

Category:	Exposure Parameters
Type & Units:	numeric (1/cm)
Default Value:	0
Range & Exceptions:	>= 0, < 1
Dependencies:	Disabled and automatically calculated if not User Defined
Description:	Atmospheric attenuation is incorporated in LHAZ computations by

using the common approximation of Beer's Law in which μ, an atmospheric attenuation coefficient (in cm^{-1}) is used to describe an exponential decay of the power or energy transmitted by the atmosphere as a function of range.

5.1.4   Reflection Exposure Parameters

Reflection Exposure Parameters	
Laser to Target Range	100 cm
Target to Observer Range	100 cm
Target Reflectance	100 %
View Angle	0 deg

Reflection Exposure Parameters

Applies only for Reflections Analyses

Laser to Target Range

Category:	Reflection Exposure Parameters
Type & Units:	Distance (mm, cm, in, ft, yd, m)
Default Value:	100 cm
Range & Exceptions:	> 0
Dependencies:	none
Description:	The range from laser to reflected target.

LHAZ assumes that the laser is hitting the surface at normal incidence for its analysis of hazards. The *Laser to Target Range* is the distance measured from the output aperture of the laser to the reflecting target. Note that this distance can be important because the beam may be attenuated by the atmosphere, and the beam diameter at the target will be influenced.

Target to Observer Range

Category:	Reflection Exposure Parameters
Type & Units:	Distance (mm, cm, in, ft, yd, m)
Default Value:	100 cm
Range & Exceptions:	> 0
Dependencies:	none
Description:	The range from reflected target to the observer.

As part of the diffuse reflection hazard assessment geometry, the user can specify a distance from the reflecting target to the viewer. The OD requirement value is computed based upon this distance. Therefore, any distance smaller than the computed NHZ will generally produce an OD requirement greater than zero. Also, the atmospheric attenuation will apply to this target to viewer range as well as the laser to target distance that the beam traverses.

Target Reflectance

Category:	Reflection Exposure Parameters
Type & Units:	Percentage OR Decimal
Default Value:	100 %
Range & Exceptions:	>= 0%, <= 100%
Dependencies:	none
Description:	The reflectance of the target, 0% - 100%.

The user can also set the target reflectance coefficient. A reflectance coefficient with values of zero (no reflectance) to one (maximum of 100% reflectance) can be assigned if known for the target material. Otherwise, the reflectance should be left at 100% as a worst-case analysis. Appendix B provides typical reflectance values for common materials.

View Angle

Category:	Reflection Exposure Parameters
Type & Units:	`double`
Default Value:	0
Range & Exceptions:	$>= 0$, < 90
Dependencies:	none
Description:	The viewing angle offset in degrees. 0 deg is the worst case, in line with the laser, which is perpendicular to the reflector. 90 degrees is completely orthogonal to the beam.

The angle from normal incidence at which the reflection is being viewed can also be specified. The angle should be left at zero degrees if the viewing geometry is unknown. This will provide the worst-case NHZ and OD requirements for the diffuse reflection exposure. LHAZ assumes that the laser is hitting the surface at normal incidence for its analysis of diffuse reflection hazards. Note that this value is not used for specular reflection hazard assessments.

5.2   ANALYSIS WINDOWS

5.2.1   MPE & Classification Analysis Window

Since this version of LHAZ is a plug-in for the AFRL/RHD Application Framework, the user has more access to the laser parameters than he had with LHAZ 4. Another difference is that each Analysis Window does not need to be the same size as the others. In LHAZ 4, each tab on the tabbed pane took up the same amount of screen real-estate as the others. We can make our analysis windows be more concise and small, so that several analysis windows might potentially be placed on the screen at the same time, along with all of the available relevant parameters.

The MPE and Classification tab in LHAZ 4.x showed 4 columns representing different potential exposure durations, and eight rows. Many of these rows did not make sense with the columns that were available (e.g. MPE for skin shown in the column representing the recommended exposure duration for ocular exposures). This data filled the tab, but the amount of information displaced overwhelmed most users. In LHAZ 5, the user can specify a user-defined exposure duration for eye exposures, or can easily adopt the standard exposure the ANSI[1] recommends. He may also specify a different exposure for diffuse/skin exposures, or use the ANSI[1] recommended value.
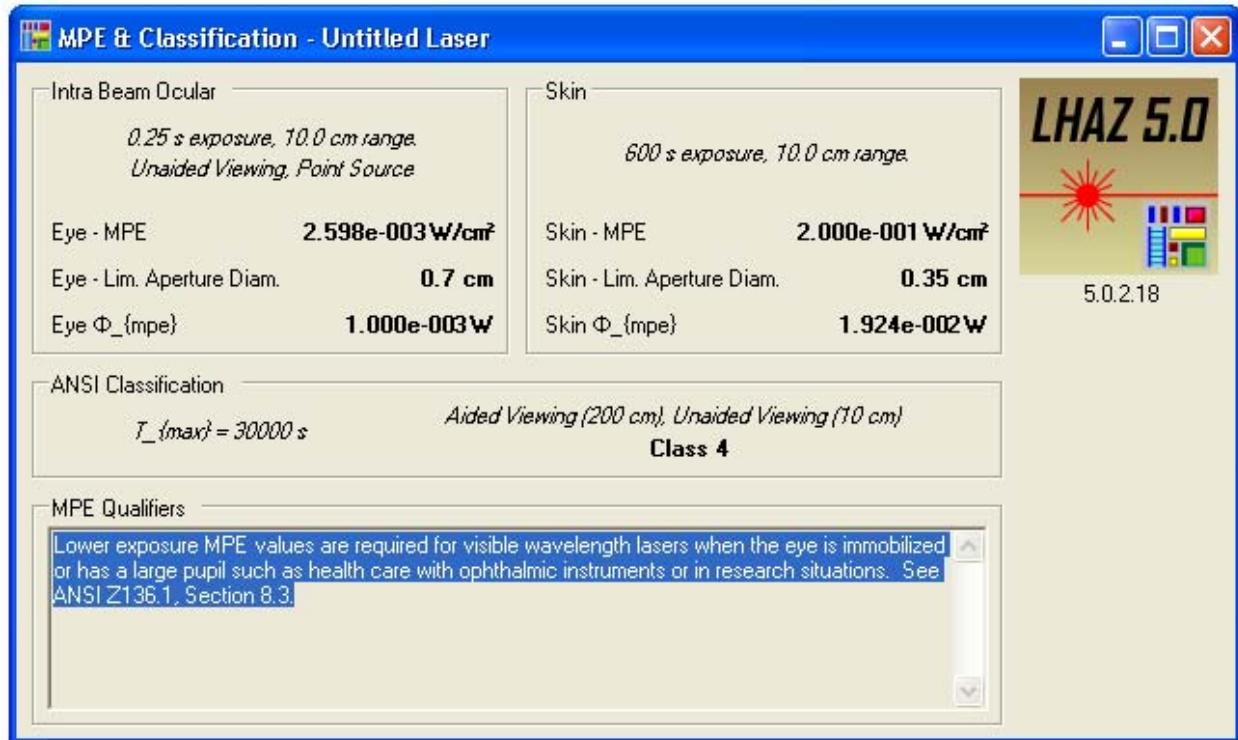
MPE & Classification Analysis Window

Title

The title of the window includes the Laser Name to assist in illustrations and reporting.

Intra Beam Ocular Parameters Summary

This section describes some of the key parameters that are relevant to the evaluation of the Intra Beam Ocular analyses, but are often overlooked. It includes the exposure duration, range, whether or not aided viewing was used, and whether or not the laser creates a point-source (the laser emitter subtends less than α_{min} on the viewer's retina) or an extended source on the retina. The user can apply the context menu to send the string to a report.

Eye - MPE

The intra beam ocular Maximum Permissible Exposure limit. The limit is expressed as Radiant Exposure (J/cm^2) per pulse for single pulse and multiple pulse lasers, or Irradiance (W/ cm^2) for CW lasers. The context menu allows simple reporting, batch reporting, and graphing.

Eye – Limiting Aperture Diameter

The ANSI Z136.1 Standard[1] uses a limiting aperture over which the laser exposure is averaged for the purposes of hazard assessment. This aperture is a circle with a diameter that is commonly specified by its diameter. The context menu allows simple reporting, batch reporting, changing local units, and graphing. The global units, "Limiting Ap. Diam." also applies to this field.

Eye – Q_{MPE}

The Q_{MPE}is simply the product of the MPE and the area of the limiting aperture. This quantity is often useful when comparing measurements to exposure limits. Note that the units are Joules (Q_) for pulsed lasers or Watts (Φ_) for CW lasers. The context menu allows simple reporting, batch reporting, and graphing.

Skin Parameters Summary

This section describes some of the key parameters that are relevant to the evaluation of the skin analyses, but are often overlooked. It includes the exposure duration, and range. The user can apply the context menu to send the string to a report.

Skin - MPE

The skin Maximum Permissible Exposure limit. The limit is expressed as Radiant Exposure (J/cm^2) for single pulse and multiple pulse lasers, or Irradiance (W/ cm^2) for CW lasers. The context menu allows simple reporting, batch reporting, and graphing.

Skin – Limiting Aperture Diameter

The ANSI Z136.1 Standard[1] uses a limiting aperture over which the laser exposure is averaged for the purposes of hazard assessment. This aperture is a circle with a diameter that is commonly specified by its diameter. The context menu allows simple reporting, batch reporting, changing local units, and graphing. The global units, "Limiting Ap. Diam." also applies to this field.

Skin – Q_{MPE}

The Q_{MPE}is simply the product of the ocular MPE and the area of the limiting aperture. This quantity is often useful when comparing measurements to exposure limits. Note that the units are Joules (Q_) for pulsed lasers or Watts (Φ _) for CW lasers. The context menu allows simple reporting, batch reporting, and graphing.

Classification T_max

The exposure duration used for both aided and unaided classification. The user can apply the context menu to send the string to a report. Note that versions of LHAZ 4 erroneously used the user defined exposure durations rather than T_{max}.

Classification

This field shows the hazard classification of the laser according to the Z136.1-2007 standard. The label for this field shows the pertinent ranges, and the user can use the context menu to send the string to a report. User–defined viewing optic parameters are NOT used in the classification procedures. The exposure duration , T_{max}, used is shown. The context menu allows simple reporting, and batch reporting.

MPE Qualifiers

This portion of the worksheet provides supplemental information referencing specific exceptions to the MPE provided in the LHAZ computation. Provided in the qualifier is a brief summary and

a reference to specific portions of the ANSI Z136.1[1] for further reading. The user can apply the context menu to send the string to a report.

5.2.2 NOHD & OD Analysis Window

The *NOHD and OD* Analysis Window allows the user to interactively compute Nominal Ocular Hazard Distance (NOHD) and Optical Density (OD) requirements for protective eyewear or other materials.
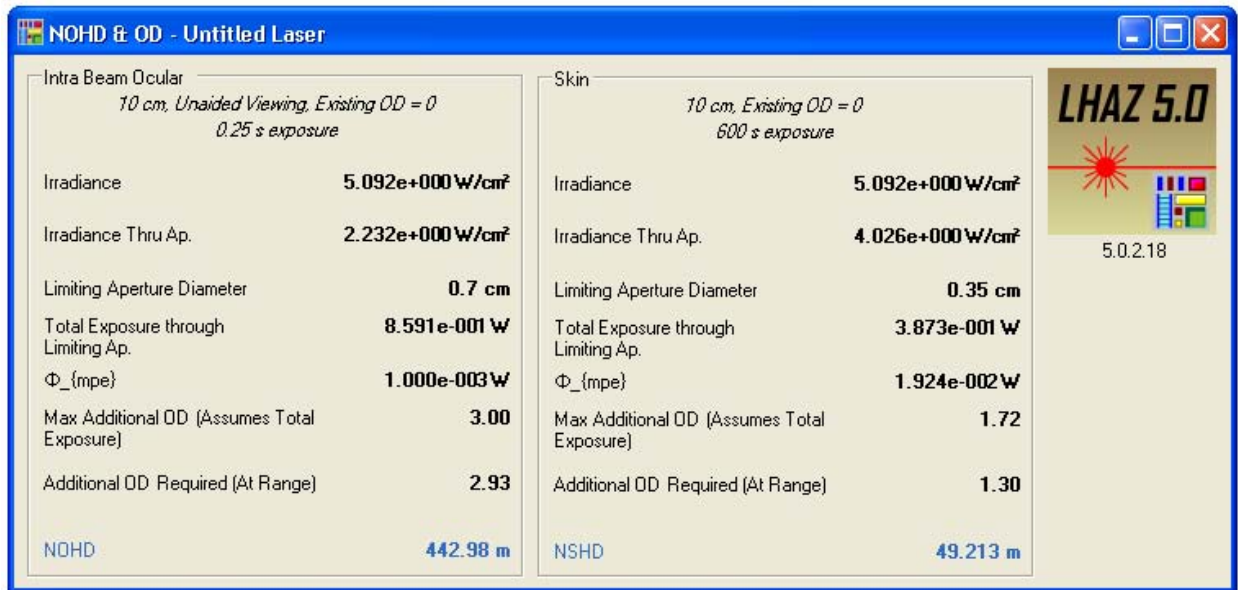
NOHD & OD Analysis Window

Title

The title of the window includes the Laser Name to assist in illustrations and reporting.

Intra Beam Ocular Parameters Summary

This section describes some of the key parameters that are relevant to the evaluation of the Intra Beam Ocular analyses, but are often overlooked. It includes the exposure duration, range, the Existing OD used, and whether or not aided viewing was used. The user can apply the context menu to send the string to a report.

Total Radiant Exposure (Intra Beam Ocular)

This result provides relative exposure levels when conducting laser hazard assessments. The result will display values in radiometric terms, which differ for pulsed, or CW lasers, i.e. Radiant Exposure (J/cm^2) or Irradiance (J/cm^2) per pulse. This value is computed from the power or energy in the beam and the area of the beam profile at the specified range. The context menu allows simple reporting, batch reporting, and graphing.

Radiant Exposure through Optics (Intra Beam Ocular)

This result provides relative exposure levels when conducting laser hazard assessments. The result will display values in radiometric terms, which differ for pulsed, or CW lasers, i.e. Radiant Exposure (J/cm^2) or Irradiance (J/cm^2) per pulse. This value is computed from the power or energy in the beam and the area of the beam profile at the specified range that actually passes through optics if aided viewing is used, and is averaged over the limiting aperture. The context menu allows simple reporting, batch reporting, and graphing.

Limiting Aperture Diameter (Intra Beam Ocular)

The ANSI Z136.1 Standard[1] uses a limiting aperture over which the laser exposure is averaged for the purposes of hazard assessment. This aperture is a circle with a diameter that is commonly specified by its diameter. This value is the same as the one in the MPE & Classification Analysis Window and is listed here for easy comparison. The context menu allows simple reporting, batch reporting, changing local units, and graphing. The global units, "Limiting Ap. Diam." also applies to this field.

Total Exposure through Limiting Ap. (Intra Beam Ocular)

This result provides relative exposure levels when conducting laser hazard assessments. The result will display values in radiometric terms, Accessible Emission in Joules per pulse for a pulsed laser or Watts for CW lasers. This value is computed taking the total Radiant Exposure through Optics (Intra Beam Ocular) and multiplying it by the area of the limiting aperture. The context menu allows simple reporting, batch reporting, and graphing.

Q_{MPE} (Intra Beam Ocular)

The Q_{MPE}is simply the product of the MPE and the area of the limiting aperture. This quantity is often useful when comparing measurements to exposure limits. Note that the units are Joules (Q_) for pulsed lasers or Watts (Φ _) for CW lasers. This value is the same as the one in the MPE & Classification Analysis Window and is listed here for easy comparison with the total exposure through the limiting aperture. The context menu allows simple reporting, batch reporting, and graphing.

Max Additional OD (Intra Beam Ocular)

The "*Maximum*" OD requirement value is a useful number in worst-case analyses. This value assumes that all laser energy is collected and transmitted by the limiting aperture, reduced only by atmospheric attenuation and the attenuation specified for any optics or LEP used. The context menu allows simple reporting, batch reporting, and graphing.

Additional OD Required (Intra Beam Ocular)

The "*Additional*" OD requirement may be less than the "*Maximum*" OD requirement at ranges where the beam diameter is greater than the diameter of the collecting optics or limiting aperture such that not all of the energy is transmitted. The context menu allows simple reporting, batch reporting, and graphing.

NOHD (Intra Beam Ocular)

The Nominal Ocular Hazard Distance (NOHD) is the range at which the total exposure the collecting optics or limiting aperture equals the Q_{MPE}. The context menu allows simple reporting, batch reporting, changing local units, and graphing. The global units, "Hazard Distances" also applies to this field.

Skin Parameters Summary

This section describes some of the key parameters that are relevant to the evaluation of the skin analyses, but are often overlooked. It includes the exposure duration, range, and the Existing OD used. The user can apply the context menu to send the string to a report.

Total Radiant Exposure (Skin)

This result provides relative exposure levels when conducting laser hazard assessments. The result will display values in radiometric terms, which differ for pulsed, or CW lasers, i.e. Radiant Exposure (J/cm^2) or Irradiance (J/cm^2) per pulse. This value is computed from the power or energy in the beam and the area of the beam profile at the specified range. The context menu allows simple reporting, batch reporting, and graphing.

Radiant Exposure through Limiting Aperture (Skin)

This result provides relative exposure levels when conducting laser hazard assessments. The result will display values in radiometric terms, which differ for pulsed, or CW lasers, i.e. Radiant Exposure (J/cm^2) or Irradiance (J/cm^2) per pulse. This value is computed from the power or energy in the beam and the area of the beam profile at the specified range that actually passes through and is averaged over the limiting aperture. The context menu allows simple reporting, batch reporting, and graphing.

Limiting Aperture Diameter (Skin)

The ANSI Z136.1 Standard[1] uses a limiting aperture over which the laser exposure is averaged for the purposes of hazard assessment. This aperture is a circle with a diameter that is commonly specified by its diameter. This value is the same as the one in the MPE & Classification Analysis Window and is listed here for easy comparison. The context menu allows simple reporting, batch reporting, changing local units, and graphing. The global units, "Limiting Ap. Diam." also applies to this field.

Total Exposure through Limiting Ap. (Skin)

This result provides relative exposure levels when conducting laser hazard assessments. The result will display values in radiometric terms, Accessible Emission in Joules per pulse for a pulsed laser or Watts for CW lasers. This value is computed taking the total Radiant Exposure through Limiting Aperture (Skin) and multiplying it by the area of the limiting aperture. The context menu allows simple reporting, batch reporting, and graphing.

Q_{MPE} (Skin)

The Q_{MPE}is simply the product of the MPE and the area of the limiting aperture. This quantity is often useful when comparing measurements to exposure limits. Note that the units are Joules (Q_) for pulsed lasers or Watts (Φ _) for CW lasers. This value is the same as the one

in the MPE & Classification Analysis Window and is listed here for easy comparison with the total exposure through the limiting aperture. The context menu allows simple reporting, batch reporting, and graphing.

Max Additional OD (Skin)

The "*Maximum*" OD requirement value is a useful number in worst-case analyses. This value assumes that all laser energy is collected and transmitted by the limiting aperture, reduced only by atmospheric attenuation and the attenuation specified for any LEP used. The context menu allows simple reporting, batch reporting, and graphing.

Additional OD Required (Skin)

The "*Additional*" OD requirement may be less than the "*Maximum"* OD requirement at ranges where the beam diameter is greater than the diameter of the collecting optics or limiting aperture such that not all of the energy is transmitted. The context menu allows simple reporting, batch reporting, and graphing.

NSHD (Skin)

The Nominal Skin Hazard Distance (NSHD) is the range at which the total exposure the collecting optics or limiting aperture equals the Q_{MPE}. The context menu allows simple reporting, batch reporting, changing local units, and graphing. The global units, "Hazard Distances" also applies to this field.

5.2.3   Reflections Analysis Window

LHAZ 5 provides for the placement of both the laser and target in the diffuse reflection hazard assessment geometry. Also included are differing exposure times from the direct beam exposure hazard analysis. An explanation of diffuse reflection hazard assessments can be found in Section 7. The reflection hazard assessment worksheet is illustrated below. The LHAZ 5 version of this Analysis Window shows the results of diffuse and specular calculations simultaneously. A diffuse reflection analysis assumes an ideal, lambertian reflector, while a specular reflection analysis assumes a flat mirror-like surface. There are a number of properties available for the reflection hazard analysis. Some of these properties are common to all hazard analysis, while some exposure parameters are specific to reflections. For the purposes of LHAZ, we have termed the hazard distance due to a diffuse or specular reflection the Nominal Hazard Zone. The distance is measured from the reflecting surface.

Reflections Analysis Window

Title

The title of the window includes the Laser Name to assist in illustrations and reporting.

Reflections Parameters Summaries

There are several places on the Analysis Window where relevant properties are reviewed and summarized to remind the user. The ones relating to the reflection geometry include the Laser to Target Range and Target to Observer Range. The eye parameters summary includes whether or not Existing OD and aided viewing are used, whereas the skin parameters just show the Existing OD. Normal accidental exposure durations are shown for specular analyses for eye and skin, whereas both eye and skin use the same Diffuse Reflection Exposure Duration. The user can apply the context menu to any of these and send the string to a report.

Beam Diameter At Target

The diameter of the beam spot on the target along the X and Y axis is shown here. This size is used to determine the angle subtended on the retina. The user can apply the context menu to send the string to a report.

Nominal Hazard Zone

Each of the four sections Specular Eye, Specular Skin, Diffuse Eye, and Diffuse Skin, show the Nominal Hazard Zone, which is the range at which the total exposure at the collecting optics or limiting aperture equals the Q_{MPE}, after it has been attenuated by atmosphere, existing OD, reflection coefficients, and lambertian diffuse reflections. If this range is less than the range from the target to the viewer, the additional OD required will always be 0. The context menu allows simple reporting, batch reporting, changing local units, and graphing. The global units, "Hazard Distances" also applies to these fields, as well as a context menu applied only to this form that changes the units for all of the NHZ fields on the form.

Additional OD

Each of the four sections Specular Eye, Specular Skin, Diffuse Eye, and Diffuse Skin, show the Additional OD required, above the existing OD, which would allow the wearer to safely withstand the exposure if they were Range Target to Viewer. The context menu allows simple reporting, batch reporting, and graphing.

6. STANDARD REPORTS

LHAZ 5 provides four standard reports. They are described in the following sections.

6.1 DEFAULT REPORT

The Default Report provides laser parameters, classification, and hazard distances.

Laser Report
AFRL HEDO Application Framework 2.5.0.38
LHAZ Plugin 5.0.0.18
LTMC Version 3.0.0
Wednesday, April 04, 2007

Laser Name: **Untitled Laser**

Laser Parameters:
    Wavelength: 532 nm
    Output Mode: CW
    Average Power: 1 W
    Energy Per Pulse: N/A
    Pulse Duration: N/A
    PRF: N/A
    Beam Profile: Circular
    Beam Distribution: Gaussian
    Beam Divergence: 0.500 mrad X N/A
    Beam Waist Diameter: 0.500 cm X N/A
    Beam Waist Range: N/A X N/A
    Output Aperture Diam: N/A X N/A
    Source Size: N/A X N/A

MPE Computations:
    Exposure Duration: 0.25 s
    Exposure Range: 10.0 cm
    MPE (Eye):   2.598e-003 W/cm2
    Limiting Aperture(Eye):   0.7 cm

6.2 WEB REPORT

The Web Report provides the same information as the Default Report, but formatted using HTML, for inclusion in a web page.

6.3   FORM 2760 REPORT

The Form 2760 Report completes AF Form 2760.

Laser Hazard Evaluation
AFRL HEDO Application Framework 2.5.0.38
LHAZ Plugin 5.0.0.18
LTMC Version 3.0.0
Wednesday, April 04, 2007

Laser Name: **Untitled Laser**

A. A hazard evaluation was accomplished for a laser with the following operational characteristics:

Laser Parameters:
    Wavelength: 532 nm
    Output Mode: CW
    Average Power: 1 W
    Energy Per Pulse: N/A
    Pulse Duration: N/A
    PRF: N/A
    Beam Profile: Circular
    Beam Distribution: Gaussian
    Beam Divergence: 0.500 mrad X N/A
    Beam Waist Diameter: 0.500 cm X N/A
    Beam Waist Range: N/A X N/A
    Output Aperture Diam: N/A X N/A
    Source Size: N/A X N/A

Viewing Conditions:
    Atm. Attenuation Coeff: N/A (1/cm)

    Aided Viewing Used: False
    Optics Transmittance: N/A
    Optics Objective Diam: N/A
    Optics Exit Diam: N/A

B. This is an ANSI Z136.1-2007 **Class 4** Laser and should be operated in accordance with
the safety measures outlined in the AFOSH STD 48-139 along with such other safety
procedures required by the responsible laser safety officer. Classification was
conducted at a range of **10.0 cm**.

Classification Analysis:

    <u>Viewing Conditions</u>   <u>Exposure Duration (s)</u>   <u>Classification</u>

6.4 CLASSIFICATION NOTES

The Classification Notes report provides a detailed description of the intermediate results of the classification procedure.

Classification Notes

Laser Name: **Untitled Laser**

Laser Parameters:
    …

MPE Computations:
    Exposure Duration: 0.25 s
    Exposure Range: 10.0 cm
    MPE (Eye):   2.598e-003 W/cm2
    Limiting Aperture(Eye):   0.7 cm
    Class 1 AEL(Eye):   1.000e-003 W

    Limiting Aperture(Skin): 0.35 cm
    MPE (Skin):   2.000e-001 W/cm2

Lower exposure MPE values are required for visible wavelength lasers when the eye is immobilized or has a large pupil such as health care with ophthalmic instruments or in research situations. See ANSI Z136.1-2000, Section 8.3.

Classification:
    Unaided Viewing: Class_4

Laser_GetAELindices(classIndex, 0.250000 s, (Condition 2), 10.000000 cm, discussion)
range = 10.000000 cm
DoC1 = 5.000000 cm, DeC1 = 0.700000 cm, magPowerC1 = 7.142857
DoC2 = 0.700000 cm, DeC2 = 0.700000 cm, magPowerC2 = 1.000000
angleSubtendedC1 = 0.000000 radians
angleSubtendedC2 = 0.000000 radians
aelPowerClass3B = 0.500000 W
aelPulseEnergyClass3B = 0.125000 J
Procedure for CW (and Single Pulse) Laser Classification
index[Class_3B] = 2.000000
Class 1 : Impossible
Class 1M: Impossible
Class 2 : Impossible
Class 2M: Impossible
Class 3R: Impossible
Class 3B: Impossible
Class 4 :

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7.   COMPUTATION METHODS

LHAZ 5 executes many calculations in order to arrive at a complete set of hazard analysis results. The following sections explain the fundamentals of the calculations performed in each analysis window and the assumptions behind the results. For the purposes of much of the discussion presented here, we will work with a gaussian profile, circularly symmetric beam so that the example computations can be compared with tractable hand calculations.

7.1   LASER PARAMETERS AND BEAM PROPAGATION

The laser parameters group of the properties grid allows the user to enter all parameters related to the laser that are necessary to complete a laser hazard analysis. These parameters describe the amount of energy or power output from the laser, and the geometry with which the beam will propagate when it exits the laser. The laser parameters are illustrated in Figure 1.. Parameter definitions can be found in Appendix E.

7.1.1   Beam Geometry
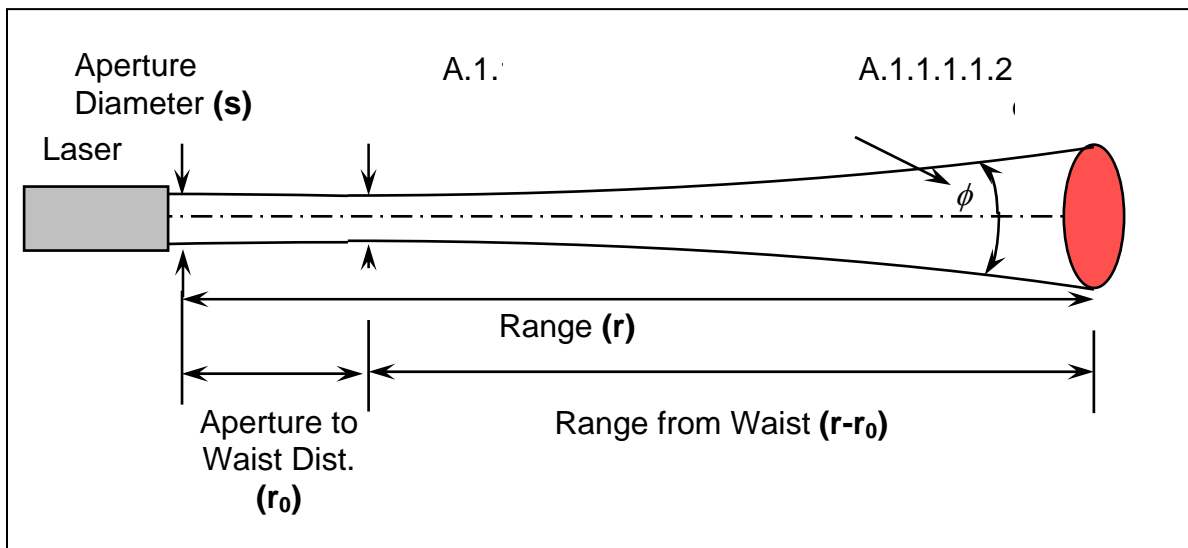
Figure 1: Laser Beam Propagation Geometry Assumed for LHAZ.

Figure 1 demonstrates the beam geometry assumed for intra-beam computations with LHAZ. This is the recommended geometry according to the ANSI Z136.1 Standard[1]. The beam is assumed to expand from a minimum beam diameter, or waist, according to a hyperbolic function. The beam diameter as a function of range along each of perpendicular, major and minor axes is described by Equation 1. Note that the beam waist position is not necessarily located at the output aperture of the laser, and that there may be differing beam waist diameters, divergences, and aperture to waist distance for each axis. Beam diameter and divergence values must be specified at the 1/e intensity points of the gaussian distribution.

$$D_L = \sqrt{a^2 + (r - r_0)^2 \phi^2}$$

Equation 1

The concept of extended sources is a bit more difficult to include and understand in the laser hazard analysis process. Basically, some laser sources when viewed appear to emit over a large area and not simply a small point. An example of an extended source emitter is an array of diode lasers closely assembled to form what appears to be a large slab of laser emission. Typically, this light cannot be focused to a small point on the retina, but will create an image that has a certain angular extent. Figure 2 illustrates an extended source image being formed on the retina.
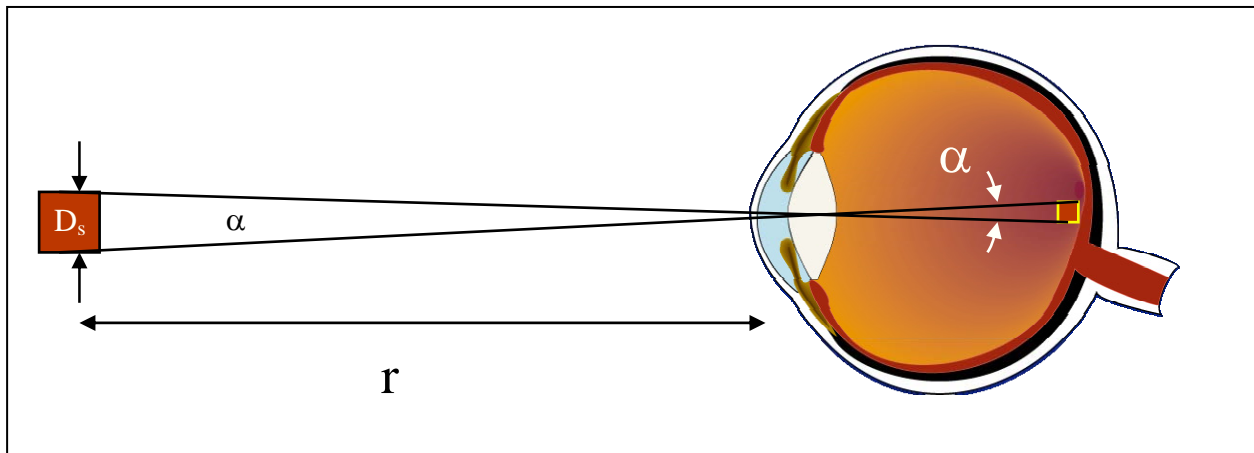
Figure 2: An extended source laser forming an image on the retina. The symbol alpha is used to denote the angle subtended by the laser source.

The *Source Size* value entered in LHAZ can have two distinct modes: a constant diameter or a constant angle subtended in the observer's vision. The mode for the extended source is determined by the units selected for the value. If the dimensions are specified in cm, then the source is assumed to have a constant diameter, and the visual angle subtended (α) can be approximated by $\alpha = \dfrac{D_s}{r}$

Equation 2. On the other hand, if the dimensions are specified in mrad, the source is assumed to subtend a constant visual angle until it reaches the diameter specified by the *Aperture Diam* value. At distances beyond this point, the visual angle subtended is given using $\alpha = \dfrac{D_s}{r}$

Equation 2 with D_s replaced by the laser output aperture diameter, *s*. Note that the laser aperture diameter has no impact on the evaluation unless a constant angular (in mrad) source size is specified.

$$\alpha = \frac{D_s}{r}$$

Equation 2

7.1.2   Pulse Mode and Pulse Parameters

Laser output is assumed to be single pulse, multi-pulse, or CW. Pulsed laser output energy (Q_0) is specified in joules per pulse, and CW output power (Φ_0) is specified in watts. Although the CW and single pulse laser outputs are self explanatory, the multi-pulse is subject to a few constraints. The multi-pulse laser hazard evaluation is limited to laser output of constant pulse repetition frequency (F), and a constant pulse duration (t) in seconds and constant energy in joules (J). This allows for the average output power of the laser to be related to the energy per pulse by $\Phi_{(avg)} = Q_0 \cdot F$

Equation 3.

$$\Phi_{(avg)} = Q_0 \cdot F$$

Equation 3

When conducting a multi-pulse laser hazard analysis, the average power should be computed and displayed in the "grayed" *Average Power* input field.

7.1.3   Beam Profile and Distribution

Three beam profile shapes and two cross-sectional distributions can be selected within LHAZ. These values allow the user to accurately depict commonly occurring beam profile shapes. The user should select the combination of profile and distribution that most accurately mimics that seen from the laser emitter.

Note that when elliptical or rectangular *Beam Profile* shapes are selected, the *Beam Geometry* group allows for values to be entered along both an X and Y-axis. Note that diameter values should be assembled such that all values along one axis are entered together.

Figure 3 depicts several measured beam profile shapes, which illustrate the values that may be selected in LHAZ. The images are labeled to allow the user to select the one that most closely represents the laser system being evaluated.
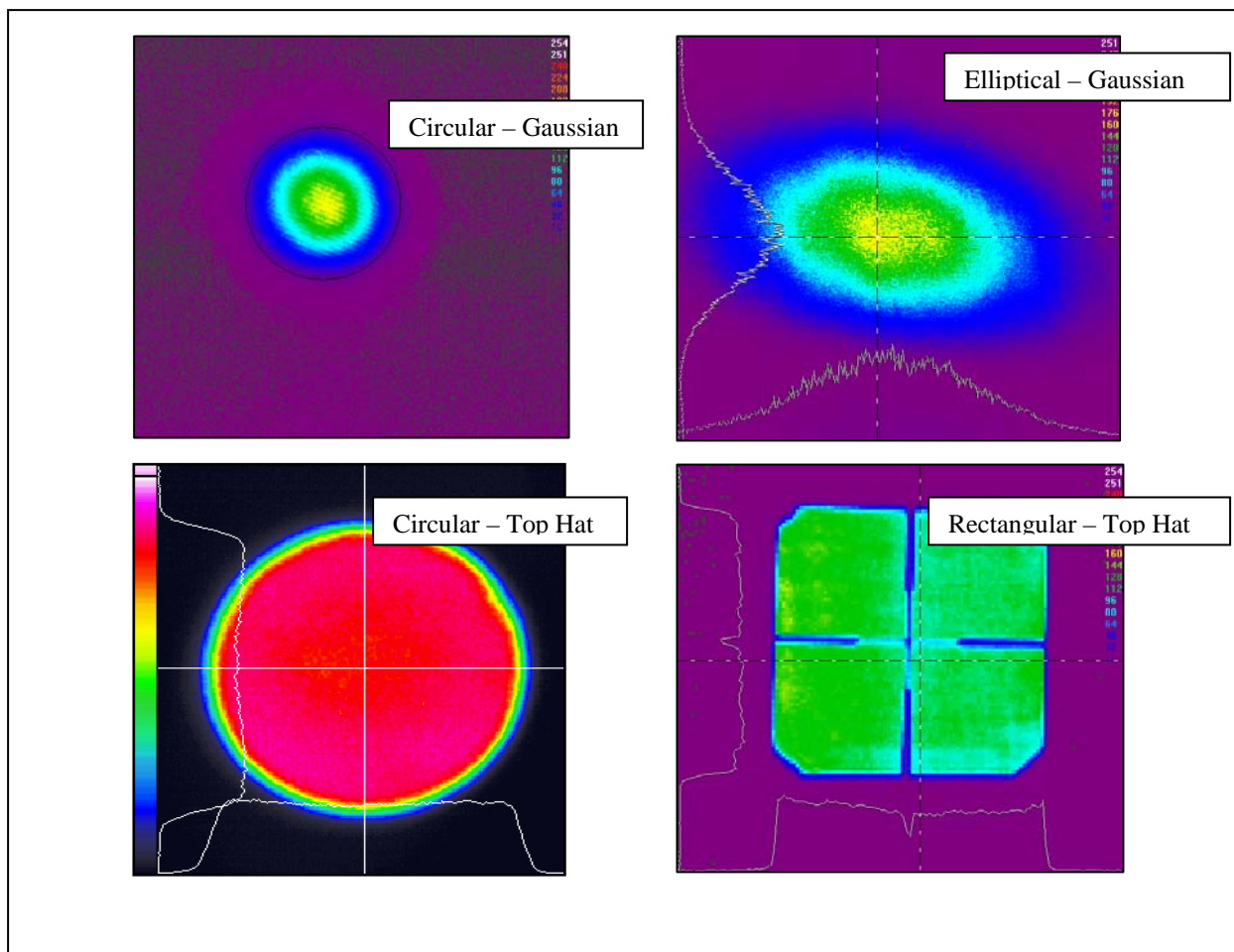
Figure 3: Examples of the various beam profile shapes that can be specified in LHAZ.

7.2   MPE CALCULATIONS AND CLASSIFICATION

LHAZ calculates the small source, extended source, and skin MPEs for CW, single-pulse, and multiple-pulse lasers. Additionally, it classifies the hazard potential of the laser according to the ANSI Z136.1 classification[1] guidelines.

7.2.1   MPE Calculations

The computation of the Maximum Permissible Exposure can depend on nearly all parameters on the *Laser Parameter* Worksheet. In most instances, the MPE will depend on wavelength of the laser, the source size (extended sources), and the pulse properties. In several wavelength ranges, the MPE will depend upon the beam diameter, and therefore the range at which the exposure is evaluated. These laser parameters are also important in the computation of MPE values for diffuse reflections that are often extended sources.

MPE computations are conducted according the ANSI Z136.1 Standard[1]. The most important section to review in order to accurately compute MPE values is Section 8 of the Standard[1].

ANSI Z136.1 Table 5a[1] and Table 5b[1] provide MPE values for ocular exposures from small sources and extended sources, respectively. ANSI Z136.1 Table 6[1] provides a number of correction factors required as intermediate steps in the computation of MPE values. ANSI Z136.1 Table 7[1] lists MPE values for skin exposures. A number of example MPE computations can also be found in Appendix B[1] of the ANSI Z136.1 Standard[1].

Limiting Aperture Diameter, commonly represented by the symbol D_f, defines the circular area over which laser power or energy is averaged for the purpose of laser hazard analysis. LHAZ uses this limiting aperture to compute the number of watts or joules of exposure present, and compares them with the value of the Class 1 AEL to determine hazard distances and optical density requirements. Note that determination of the limiting aperture diameter for a multi-pulse hazard assessment can be tricky, and the reader is encouraged to read a recent paper on the subject.

The fourth value, the Class 1 AEL is a convenient value for comparisons of exposure limits to measurements, and is used in the determination of the Classification of the laser system. The Class 1 AEL is computed using Equation 4 and is equivalent to the MPE multiplied by the area of the limiting aperture.

$$AEL_{Class\ 1} = MPE \cdot \frac{\pi \cdot D_f^2}{4}$$

Equation 4

The fifth row in the *MPE and AEL* group is the limiting aperture diameter for skin exposures. This is followed by the MPE for skin exposures. The skin exposure MPE is computed using Table 7 of the ANSI Z136.1 Standard[1].

It is beyond the scope of this manual to provide detailed procedures and associated equations for the accurate determination of MPE values in all situations. The user of LHAZ is assumed to be relatively experienced in laser safety. However, if a difficult computation arises or if an interpretation of the ANSI Z136 Standard[1] is required, the user should feel free to contact the Optical Radiation Safety Team using the contact information listed in Appendix F. We have in many cases assembled detailed tutorials on a number of specific topics such as multiple pulse laser hazard assessment and extended source MPE computation.

7.2.2   Laser Classification

The hazard class of a laser system determines required administrative and engineering control measures. Therefore, a critical step in hazard assessment is the assignment of the proper laser hazard classification. The laser hazard classification will determine not only the level of concern for user safety, but could also have a financial impact on manufacturing, installation, and field use of the laser. For example, a Class 3B[1] laser system may require that users have an eye exam as part of the administrative control measures, while a Class 3R[1] laser system may not. This can be a significant financial burden in large organizations such as the military, which requires these eye exams. A second example would be the additional engineering control measure of interlocks on protective housings for Class 3B[1] or Class 4[1] lasers.

Section 3 of the ANSI Z136.1 standard[1] contains AELs for each of the primary laser classifications – 1 through 4. The Class 1 laser is the least hazardous, the Class 4 laser most dangerous. The ANSI Z136.1 standard[1] also includes selected examples directly relevant to laser classification in Appendix B, Section B4.

The classification scheme established by the ANSI Z136.1 standard[1] is based upon the laser beam's capability to injure personnel. This capability to cause injury is determined through a comparison of the "Accessible Emission" or "Accessible Radiation" from the laser to an established limit for each class. If the limit is exceeded, the laser falls into at least the next more hazardous class. Each of these limits is therefore termed an "Accessible Emission Limit" or AEL.

Four primary laser classes are used to separate the capability of lasers to cause injury into easily discernable categories. Both administrative and engineering control measures have been established commensurate with the hazards of each category. Section 4 of ANSI Z136.1 Standard[1] contains detailed recommendations and requirements for these control measures for each class of laser, with a summary provided in Table 10[1].

Laser Classification procedures have changed in LHAZ 5.0 to reflect changes in the ANSI Z136.1 Standard[1]. The updated classification procedure is described in Appendix C.

Note that the updated classification procedure uses ranges for both Condition 1 (aided viewing possible) and Condition 2 (unaided viewing). LHAZ 5.0 computes default value for both of these. Currently, the user overrides the default value of one of these using the Eye Range property. The user may provide a user-defined value for this, or accept the value computed (based on the Eye Exp. Duration property). If the Use Aided Viewing property is True, then this value is used in place of the default Condition 1 range. If it is False, then it is used in place of the default Condition 2 range.

7.3   NOHD AND OD CALCULATIONS

The *NOHD and OD* window is a straightforward, easy-to-use safety information page.
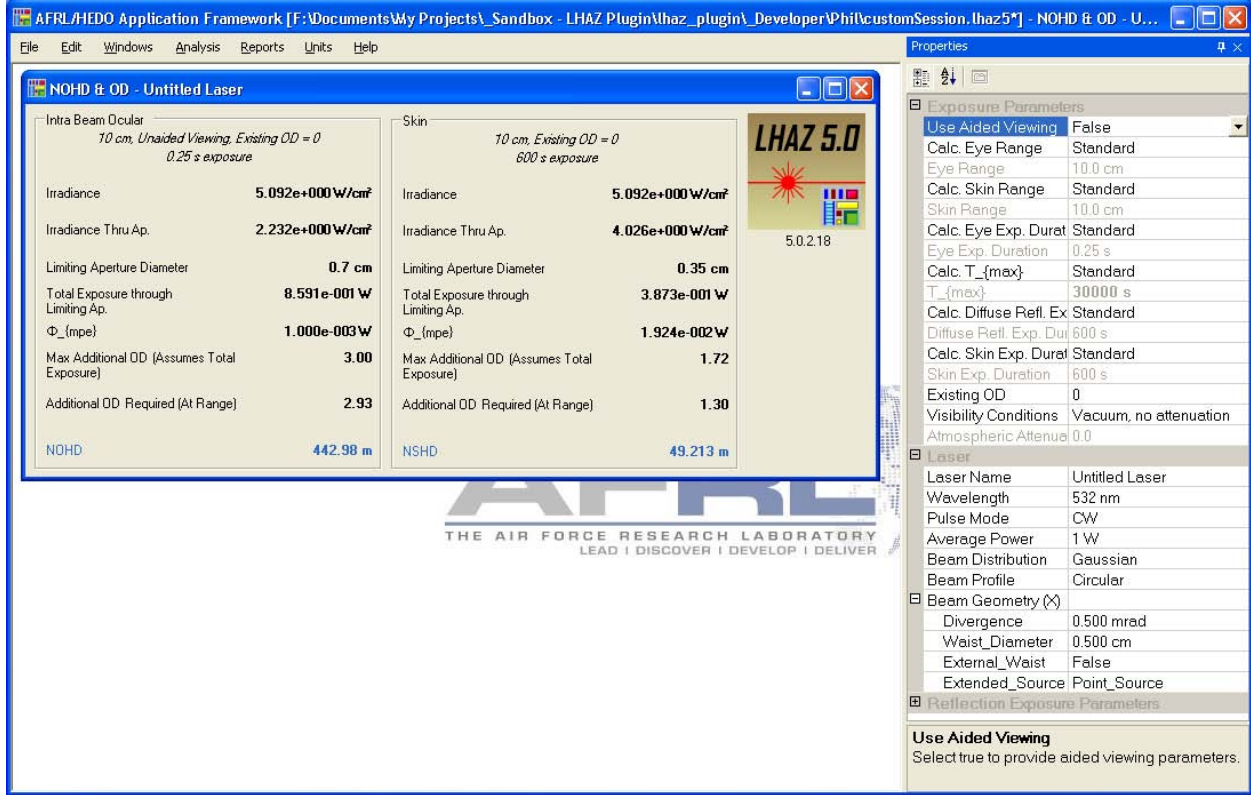
7.3.1   NOHD Computations

The method for computing intra-beam NOHD values within LHAZ involves the computation of power or energy transmitted by the limiting aperture as a function of range and determining the point at which the exposure drops below the MPE. The method is outlined in Example 39 of the ANSI Z136.1 Standard[1]. For example, a circular-gaussian beam profile, the power or energy transmitted by an aperture of diameter D_f is given by Equation 5 and Equation 6.

$$\Phi_f = \Phi_0 \left[1 - e^{-\left(\frac{D_f^2}{a^2 + (r - r_0)^2 \phi^2} \right)} \right]$$

Equation 5

$$Q_f = Q_0 \left[1 - e^{-\left(\frac{D_f^2}{a^2 + (r - r_0)^2 \phi^2} \right)} \right]$$

Equation 6

Equation 5 and Equation 6 can each be solved for r, with the appropriate Φ_{MPE} or Q_{MPE} substituted for Φ_f and Q_f to obtain the hazard distance. Solving for r, and labeling this range as r_{HD}, we obtain Equations 12a and 12b for CW and pulsed lasers respectively.

$$r_{HD} = r_0 + \frac{1}{\phi} \sqrt{ \frac{-D_f^2}{\ln\left(1 - \frac{\Phi_{MPE}}{\Phi_0} \right)} - a^2 }$$

Equation 7

$$r_{HD} = r_0 + \frac{1}{\phi} \sqrt{ \frac{-D_f^2}{\ln\left(1 - \frac{Q_{MPE}}{Q_0} \right)} - a^2 }$$

Equation 8

Equation 7 and Equation 8 work very well, although they initially seem rather complex. They compare the MPE directly to the energy or power transmitted by the limiting aperture, and do not suffer from special averaging problems for small beams. Note that Equation 7 and Equation 8 apply only to circular gaussian profile beams, and must be re-derived for other beam profile models. These equations and methods are beyond the scope of this manual.

7.3.2   Optical Density Computations

The optical density (D_λ) is an expression of the logarithm of the reciprocal of the transmittance (τ_λ) of an optical element. An equation for this definition is given below.

$$D_\lambda = \log_{10} \frac{1}{\tau_\lambda}$$

Equation 9

In order to determine the optical density requirement for a given laser exposure, our goal is to choose a transmittance of laser power or laser pulse energy through our limiting aperture that allows an amount of energy equal to the MPE in terms of power or energy to pass through the filter and limiting aperture combined. Since transmittance is simply the ratio of "power out" to "power in" we can state this as shown in Equation 10 and Equation 11.

$$\tau_\lambda = \frac{\Phi_{MPE}}{\Phi_f}$$

Equation 10

$$\tau_\lambda = \frac{Q_{MPE}}{Q_f}$$

Equation 11

These apply to CW and pulsed lasers, respectively. Replacing transmittance (τ_λ) in our definition of optical density above, in Equation 9, we obtain Equation 12 and Equation 13 for CW and pulsed lasers, respectively. Note that the notation Φ_{MPE} is shorthand for the AEL in terms of power.

$$D_\lambda = \log_{10}\left[\frac{\Phi_f}{\Phi_{MPE}}\right]$$

Equation 12

$$D_\lambda = \log_{10}\left[\frac{Q_f}{Q_{MPE}}\right]$$

Equation 13

Also note that Φ_f and Q_f can be computed at any range by incorporating the beam diameter at that range. In order to determine optical density requirements at range for a given laser, a model for the propagation of the beam must be specified. LHAZ determines Q_f and Φ_f for the exposure in question. As an example, for a circular gaussian beam distribution, Equation 5 and Equation 6 can be used.

LHAZ 4 also provides a value labeled Maximum under the OD values. This value is computed by substituting the power or energy of the laser for Φ_f or Q_f. The value is corrected only for atmospheric loss and transmittance of any optics used for aided viewing.

7.3.3   Atmospheric Attenuation

Atmospheric attenuation is incorporated in LHAZ computations by using the common approximation of Beer's Law in which μ, an atmospheric attenuation coefficient (in cm^{-1}) is used to describe an exponential decay of the power or energy transmitted by the atmosphere as a function of range, r. The equations below describe the relationship in terms of power or energy.

$$\Phi = \Phi_0 \cdot e^{-\mu \cdot r}$$

Equation 14

$$Q = Q_0 \cdot e^{-\mu \cdot r}$$

Equation 15

Note that these equations are applied to any distance that the beam propagates, including distances from diffuse reflectors to the viewers.

7.3.4 Optically Aided Viewing

When optical viewing aides such as binoculars or telescopes are used to view the laser from within the beam (intra-beam viewing), the hazard is increased by as much as the square of the magnifying power. The addition of optics, which will typically collect light over a much larger aperture than the naked eye, can significantly increase optical density requirements and hazard distances. The transmittance of the optical device must also be included, as they may attenuate the beam significantly. Most optics will transmit light effectively in the visible and near-infrared portions of the spectrum. Nominal values for the transmittance of optical viewing aids have been provided in the ANSI Z136.1 Standard[1] in Table 9[1] and are default values for LHAZ. Figure 4 illustrates the basic parameters associated with an optical viewing aid.
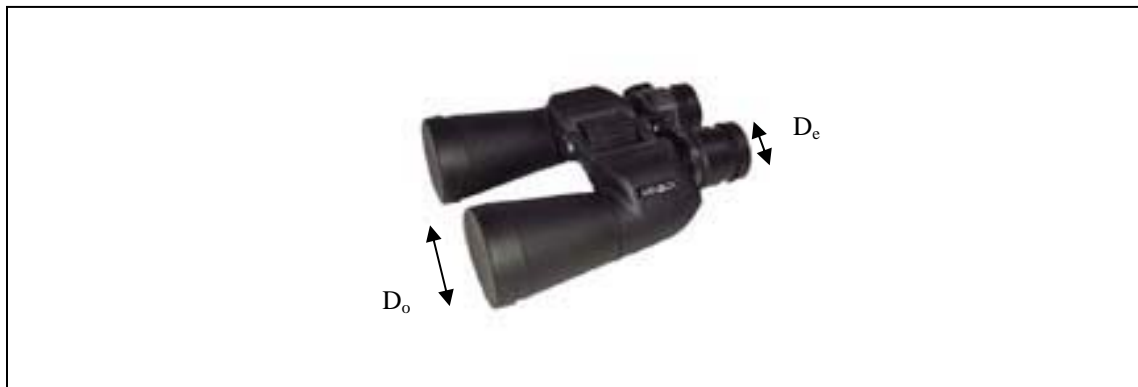
Figure 4: Parameters associated with aided viewing hazard analyses.

The Gain (G) of an optical system is the ratio of the radiant exposure or irradiance at the cornea when viewing is aided by an optical system. It is defined by Equation 16 below.

$$G = \left(\frac{D_0}{D_e} \right)^2 = P^2$$

Equation 16

Commonly, 7x50 binoculars have a power of 7.0 and an exit port diameter slightly larger than 7.0 mm. The gain for these optics is therefore approximately 49. This gain factor represents the maximum increased hazard from a laser beam due to the concentration of power or energy by the optical device.

The gain factor (G) alone does not account for all of the internal transmittance losses in the optical system. All optical systems transmit some amount less than 100%. A transmittance

value assigned the symbol τ_λ is used to correct the gain of the system and is multiplied by G. The subscript λ emphasizes that the transmittance will be a function of laser wavelength.

When viewing laser sources at closer distances, the laser beam diameter (D_L) may be less than the diameter of the collection optic (D_0). Also, optical devices with a power greater than seven often have an exit port diameter (D_e) that is less than 7-mm in diameter. In order to account for the amount of light collected and to be applied to a hazard analysis, a "collecting aperture" with diameter D_c is defined as the minimum of the entrance diameter of the optics and the optical power multiplied by the exit aperture diameter (De).

$$D_c = \min\left(D_0, P \times D_e\right)$$

Equation 17

This collection aperture can be used to define an "effective gain" when coupled with the transmittance of the optical instrument and the minimum of the two values D_c and D_L are used for D_0 in Equation 16.

$$G_{eff} = \tau_\lambda \times \left[\frac{\min\left(D_c, D_L\right)}{D_f}\right]^2$$

Equation 18

It is important to remember the definition of effective gain. The effective gain is a multiplicative factor representing the increase or (or possible decrease if τ_λ is small) in the effective irradiance or radiant exposure that is incident on the limiting aperture.

The derivation of equations for the NOHD and optical density requirements when optical aids are present requires the computation of an effective collection aperture. Also, the transmittance of the optics must be taken into account.

In order to account for the amount of light collected and to be applied to a hazard analysis, a collecting aperture with diameter D_k is defined as the minimum of the entrance diameter of the optics and the optical power multiplied by the minimum of the limiting aperture diameter (D_f) and the exit aperture diameter (D_e). The extra step of considering the limiting aperture diameter is included because in some cases the limiting aperture diameter will be less than the exit aperture of the optical device.

$$D_k = \min\left(D_0, P \times \min\left[D_e, D_f\right]\right)$$

Equation 19

This aperture diameter (D_k) is then used in place of D_f in Equation 5 and Equation 6 and in the derivation of Equation 7 and Equation 8. It is the effective collection aperture diameter for the purposes of determining the energy or power to be compared to Φ_f or Q_f. The total energy or total power is also multiplied by a factor of τ_λ to compensate for the transmittance of the optics.

Completion of the derivations yields equations for the optical density as a function of range, and for NOHD.

Combining the effects of aided viewing and atmospheric transmittance, we can derive equations for the NOHD. Again, for a circular, gaussian profile beam Equation 20 and Equation 21 give the result that LHAZ will use. Note that these equations include r_{HD} on both the right and left-hand side of the equation. This is because the r_{HD} cannot be isolated algebraically. This type of equation is known as a transcendental equation, and must be solved numerically. Fortunately, this type of equation can be solved quickly by a computer, and numerical methods for doing so have been implemented in LHAZ, making the extensive work transparent to the user.

$$r_{HD} = r_0 + \frac{1}{\phi} \sqrt{ \frac{-D_k^2}{\ln\left(1 - \frac{\Phi_{MPE}}{\Phi_0 \cdot \tau_\lambda \cdot e^{-\mu \cdot r_{HD}}}\right)} - a^2 }$$

Equation 20

$$r_{HD} = r_0 + \frac{1}{\phi} \sqrt{ \frac{-D_k^2}{\ln\left(1 - \frac{Q_{MPE}}{Q_0 \cdot \tau_\lambda \cdot e^{-\mu \cdot r_{HD}}}\right)} - a^2 }$$

Equation 21

Similar derivations can be developed for the determination of optical density requirements and the exposure at a given distance can be compared to the MPE for the specified laser parameters. Equation 22 and Equation 23 provide the equations again for our example of a circular, gaussian profile beam.

$$D_\lambda = \log_{10}\left[\frac{\Phi_0 \cdot \tau_\lambda \cdot e^{-\mu \cdot r}\left(1 - e^{-\left(\frac{D_k^2}{a^2 + \phi^2 (r - r_0)^2}\right)}\right)}{\Phi_{MPE}} \right]$$

Equation 22

$$D_\lambda = \log_{10}\left[\frac{Q_0 \cdot \tau_\lambda \cdot e^{-\mu \cdot r}\left(1 - e^{-\left(\frac{D_k^2}{a^2 + \phi^2 (r-r_0)^2}\right)}\right)}{Q_{MPE}}\right]$$

Equation 23

7.4   DIFFUSE/SPECULAR REFLECTION HAZARD ANALYSIS

The changes in LHAZ from version 3.0 to 4.2 have included additional parameters for the analysis of diffuse reflection hazards. The user can now specifically indicate the exposure time for the diffuse reflection hazard assessment, with values recommended from the ANSI standard[1] provided. Also, the distance from the laser to the target, and the distance from the viewer to the target can be specified. The target reflectance can be specified. Aided viewing effects are accurately incorporated.

The Z136.1 standard contains several revisions for extended source hazard assessments. These have increased the complexity of the extended source hazard assessment, which commonly comes into play for diffuse reflection hazard assessment. LHAZ 4.0 and 4.2 have incorporated these changes, and provides the user with an up-to-date hazard analysis tool.

In addition to diffuse reflection hazard analysis, LHAZ also provides for the computation of a limited specular reflection analysis. This analysis is limited to planar specular reflectors, which are assumed to be larger in diameter than the laser beam.

7.4.1   Diffuse Reflection Analysis Geometry

The beam propagation and reflection geometry for diffuse reflection hazard analysis is illustrated in Figure 5. The laser beam is assumed to be incident on the diffusely-reflecting surface at a right-angle to the plane of the surface, or normal incidence. The laser beam propagates from the output aperture of the laser to the target, and may lose energy or power due to atmospheric transmission losses. The observer is assumed to be positioned at a distance r_1 from the reflecting target, at an angle Θ_v as measured between the laser beam and the line from the center of the laser beam on the target. The beam diameter at the target is assigned the symbol D_ρ. The target reflectance is given a value of between zero and one and is labeled ρ.
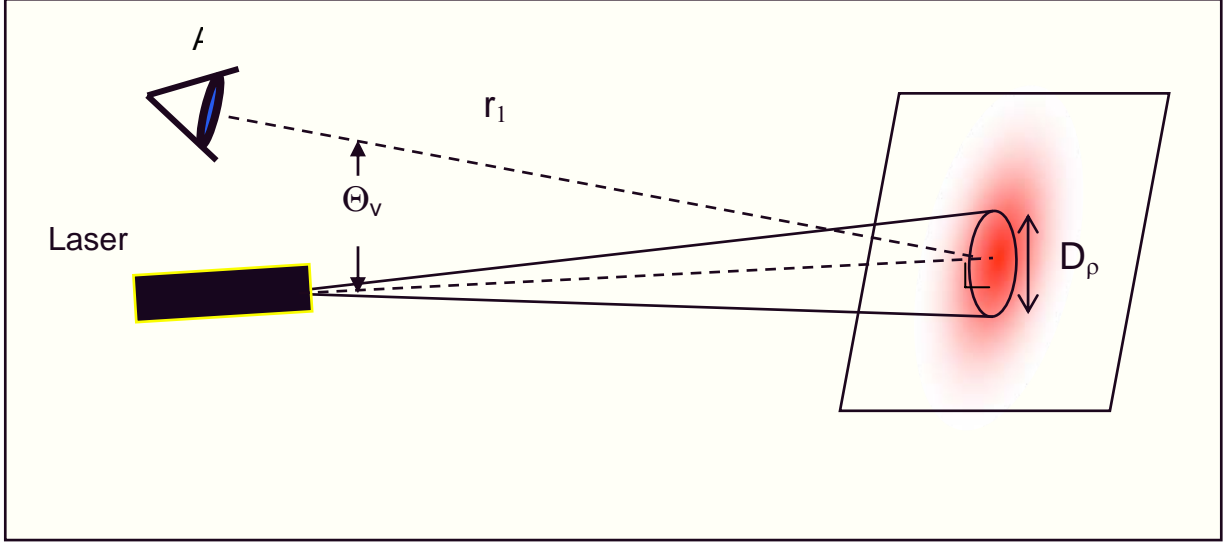
Figure 5: Laser-target-viewer geometry for diffuse reflection hazard analysis.

7.4.2 Diffuse Reflection Exposures

Within LHAZ, diffuse reflections are modeled according to Lambert's Law. This assumes that the diffusely reflecting surface is an ideal diffuse reflector and the Irradiance or radiant exposure at the observer's location can be modeled according to Equation 24 or Equation 25, respectively.

$$E_{Obs} = \frac{\Phi_0 \cdot \exp(-\mu \cdot (r + r_1)) \cdot \rho_\lambda \cos \Theta_v}{\pi r_1^2}$$

Equation 24

$$H_{Obs} = \frac{Q_0 \cdot \exp(-\mu \cdot (r + r_1)) \cdot \rho_\lambda \cos \Theta_v}{\pi r_1^2}$$

Equation 25

The MPE for a diffuse reflection must often be modeled as an extended source, as the entire illuminated surface becomes an emitter of laser energy. The angle subtended by this diffuse reflection can be approximated by Equation 26 for small angles. When combined with the exposure duration and wavelength, MPE values for diffuse reflections can often be functions of radiance, which must also be computed for the diffusely reflecting source.

$$\alpha = \frac{D_\rho}{r_1}$$

Equation 26

7.4.3 Diffuse Reflection Nominal Hazard Zone

By substitution of the MPE for the exposure in Equation 24 and Equation 25, and solving for r_1, a basic equation for the hazard distance from a diffuse reflection can be derived. The result is Equation 27, shown below.

$$r_{NHZ-Diffuse} = \sqrt{\frac{\Phi_0 \cdot \exp(-\mu \cdot (r + r_1)) \cdot \rho_\lambda \cos\Theta_v}{\pi \cdot MPE}}$$

Equation 27

The difficulty with Equation 27 is that the MPE may be a function of the visual angle subtended (α), and depending upon the value of α, different MPE equations may apply. For example, examination of Table 5b[1] of the ANSI standard[1] reveals that the correction factor C_E applies to any source subtending an angle of greater than 1.5 mrad for laser wavelengths that are in the retinal hazard region of 400 to 1400 nm.

LHAZ addresses this problem through a numerical solution. Knowing that the worst-case hazard distance is achieved by assuming that the MPE is a small source ($\alpha < 1.5$ mrad), the NHZ is estimated using Equation 27 with an MPE value from Table 5a. LHAZ then uses a numerical procedure to determine the hazard distance iteratively by testing extended source MPE values at various ranges.

Note that LHAZ will apply the atmospheric attenuation coefficient to the laser energy that is scattered from the diffuse reflector. This creates yet another reason for numerical solution as the equation is transcendental, as is seen for intra-beam NOHD computations.

The hazard distance for the diffuse reflection is labeled as an NHZ, in order to differentiate the hazard distance from that of an intra-beam exposure.

7.4.4   Diffuse Reflection Optical Density Requirements

The optical density computation for a diffuse reflection is much more straight-forward. Because the exposure distance is pre-determined, the MPE can be computed for the reflection even if it is an extended source. The exposure in W/cm^2 or J/cm^2 can be compared with this MPE and the OD requirement can be computed using Equation 28 or Equation 29.

$$D_\lambda = \log_{10}\left[\frac{E_{obs}}{MPE:E}\right]$$

Equation 28

$$D_\lambda = \log_{10}\left[\frac{H_{obs}}{MPE:H}\right]$$

Equation 29

For these two equations the value of E_{obs} or H_{obs} can be computed using Equation 24 or Equation 25 for CW and pulsed laser analysis, respectively.

7.4.5   Notes on Aided Viewing of Diffuse Reflections

LHAZ also includes the option of including optical viewing aids in the performance of diffuse reflection hazard analyses. For these computations, the viewing aid is assumed to increase the amount of laser energy collected by a multiplicative factor equal to the effective gain for the

system, as given by Equation 18. Note that this equation includes the losses due to the optical transmittance of the viewing aid. Also, the visual angle a, subtended by the diffuse reflection is assumed to increase proportionally to the magnification specified for the optics.

7.4.6 Specular Reflection Analysis

The analysis geometry for specular reflections is illustrated in Figure 6. The analysis is identical to that described for intra-beam NOHD and OD values in section 5.3, with two minor exceptions.

- The laser beam is attenuated through multiplication by the target reflectance coefficient, ρ.
- The hazard distance is computed as the farthest range from the target for which the MPE is not exceeded.
- The optical density requirement is computed based upon the beam diameter at a net range of $(r+r_1)$.
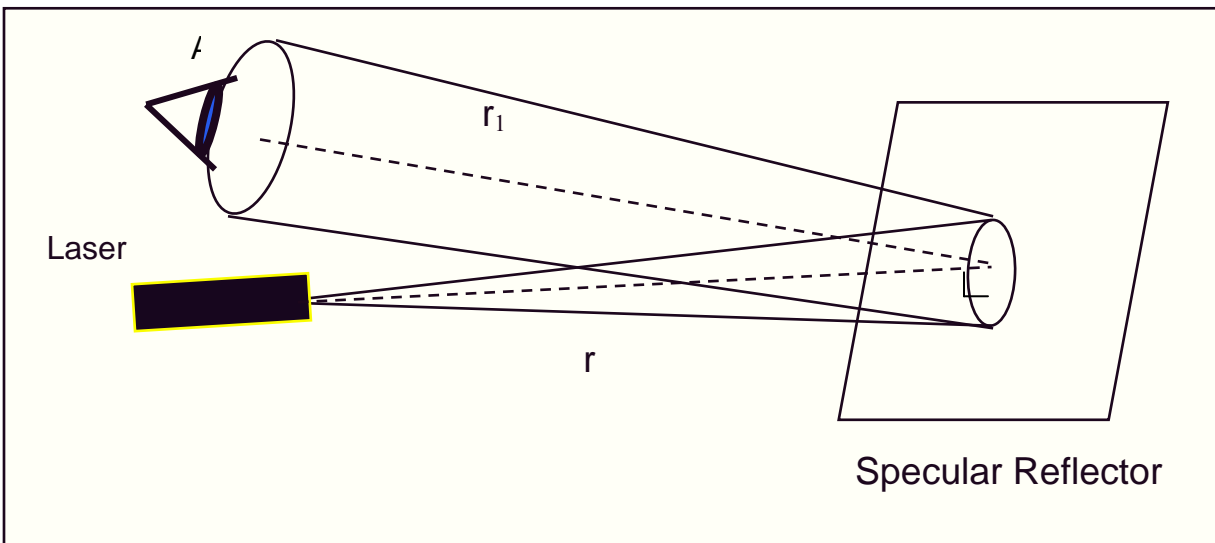
Figure 6. Hazard Analysis Geometry for a Specular Reflection.

8. LASER PARAMETER FILE FORMAT

The LHAZ Plugin 5.0 file format (.afs file) is an XML file. We do not anticipate that users will have the requirement to access these files with any application other than LHAZ. Should access to the files be urgently required, guidance on accessing these files can be provided by AFRL/RHDO.

LHAZ, version 4.6 and earlier, files cannot be read by LHAZ 5.0

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9.   REFERENCES

1.   American National Standards Institute. (2007). American National Standard for Safe Use of Lasers. ANSI Z136.1, Laser Institute of America, Orlando, FL.

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APPENDIX A   EXAMPLES

In this section, a few detailed examples are presented that illustrate the analysis process used in laser safety, and shows how LHAZ can be used to simplify this process. Section A of each example presents a "by hand" analysis, and section B illustrates how to do the same analysis using LHAZ.

NOTE: This is not a tutorial in laser safety analysis. It is assumed the reader is familiar with the topic. For those not familiar, numerous examples of laser safety analyses can be found in Appendix B of ANSI Z136.1 standard. It is also assumed that the reader has read the LHAZ manual and is familiar with the operation of the software.

A.1   EXAMPLE 1

Given a multiple-pulse laser target designator with the following parameters:

Parameter	Value	Parameter	Value
Wavelength (λ)	1064 nm	Beam Waist Diameter (a)	1.0 cm
Pulse Width (t)	20 ns	Beam Divergence (ϕ)	1.0 mrad
Pulse Repetition Frequency (F)	20 Hz	Aperture to Beam Waist Distance (r_0)	0.0 cm
Pulse Energy (Q_0)	500 mJ	Beam Profile/Shape	Circular - Gaussian
Source Size	0 cm	Aperture Diameter	2.0 cm

Compute the ocular per pulse MPE, the NOHD, and the OD required for viewing at a distance of 20 cm from the aperture. Assume unaided intra-beam viewing, a maximum time of anticipated direct exposure of T_{max}= 10 s, and no atmospheric attenuation or viewing optics.

A. By Hand Results

<u>MPE</u>

The MPE for a multiple-pulse exposure is computed using the "Three-Rule" method described in the ANSI Z136.1 Standard. The relevant parameters and steps are shown below.

Rule 1: Single Pulse MPE
a. The pulse duration (*t*) is 16-ns (16 x 10^{-9} sec).
b. For a 16-ns, 1064-nm pulse, we find in Table 5a and Table 6 of the ANSI Standard:

$$MPE : H = 5.0 \times C_c \times 10^{-6} J \cdot cm^{-2}$$

$$C_c = 1.0$$

c. This is the single pulse MPE and is expressed in J cm^{-2}, so we label it MPE_1

$$MPE_1 = 5.0 \times 10^{-6} J \cdot cm^{-2}$$

d. The limiting aperture for a 1064 nm, 16-ns ocular exposure found in Table 8 is

$$D_f = 7.0 \ mm$$

e. The value of Q_{MPE-1} is computed using MPE_1 and the limiting aperture.

$$Q_{MPE-1} = MPE_1 : H \cdot \frac{\pi \cdot D_f^2}{4}$$

$$Q_{MPE-1} = 5.0 \times 10^{-6} J \cdot cm^2 \cdot \frac{\pi \cdot (0.70 \, cm)^2}{4}$$

$$Q_{MPE-1} = 1.92 \times 10^{-6} J$$

Rule 2: Average Power MPE

a. The recommended total exposure time (T) for an inadvertent exposure to a 1064-nm laser is 10 seconds from Table 4a. We choose this value because the exposure is specified as T_{max} in the problem statement.

b. The MPE for a 10-second exposure to a 1064 nm laser from Table 5a and Table 6 of the ANSI Standard is (note convention of time interval).

$$MPE : E = 5.0 \times C_c \times 10^{-3} W \cdot cm^{-2}$$

$$MPE : E = 5.0 \times 1.0 \times 10^{-3} W \cdot cm^{-2}$$

$$MPE : E = 5.0 \times 10^{-3} W \cdot cm^{-2}$$

Labeling this MPE$_{CW}$, we have

$$MPE_{CW} = 5.0 \times 10^{-3} W \cdot cm^{-2}$$

c. For a 10-second exposure, MPE_{CW} can be converted to a radiant exposure as

$$MPE : H = (MPE : E) \cdot T$$

$$MPE : H = 5.0 \times 10^{-3} W \cdot cm^{-2} \times 10 \text{ sec}$$

$$MPE : H = 5.0 \times 10^{-2} J \cdot cm^{-2}$$

$$MPE_{CW} = 5.0 \times 10^{-2} J \cdot cm^{-2}$$

d. We must compute n from the equation given for the special case since the wavelength is 1064 nm. Here $T_2 = 10$ sec, because we have a small source laser.

$$n = F \cdot \min (T, T_2)$$

$$n = (20 Hz \cdot 10 s)$$

$$n = 200$$

e. Now we compute the MPE per pulse for the repetitively pulsed laser.

$$MPE_2 = \frac{MPE_{CW}}{n}$$

$$MPE_2 = \frac{5.0 \times 10^{-2} J \cdot cm^2}{200}$$

$$MPE_2 = 250 \times 10^{-6} J \cdot cm^2$$

f. The limiting aperture diameter for a 10-second, 1064-nm exposure is found from Table 8 of the ANSI Standard to be

$$D_f = 7.0 \ mm$$

g. The value of Q_{MPE} for the pulse group, Q_{MPE-2} is next computed.

$$Q_{MPE-2} = MPE_2 \cdot \frac{\pi \cdot D_f^2}{4}$$

$$Q_{MPE-2} = 250 \times 10^{-6} \cdot \frac{\pi \cdot (0.70 cm)^2}{4}$$

$$Q_{MPE-2} = 9.6 \times 10^{-5} J$$

h. Since the PRF is constant and there are no other pulse groupings, this is our only Q_{MPE-2}.

$$Q_{MPE-2} = 9.6 \times 10^{-5} J$$

Rule 3: Thermal Correction Factor MPE

a. We will be computing an MPE based upon the equation

$$MPE_3 = \frac{\left(n_{eff}\right)^{-0.25} \cdot MPE_{TSP}}{k}.$$

We must determine n_{eff}, k, and MPE_{TSP}.

b. Since $t_{min} = 50 \times 10^{-6}$ sec for 1064 nm, and our pulse duration has the value $t = 16 \times 10^{-9}$ sec, we use the case 2.a. ($t < t_{min}$) and MPE_{TSP} is the MPE for $t = 1$ ns. From Table 5a and Table 6 (noting our conventions for time intervals with $t = 1$ ns), we obtain

$$MPE : H = 5.0 \times C_c \times 10^{-6} J \cdot cm^{-2}$$

$$C_c = 1.0$$

$$MPE : H = 5.0 \times 10^{-6} J \cdot cm^{-2}$$

$$MPE_{TSP} = 5.0 \times 10^{-6} J \cdot cm^{-2}$$

c. To determine k and n_{eff}, we use the procedure listed in the text above and first get k, the number of pulses that occur within t_{min}.

$$k = F \cdot \min(t_{min}, T)$$

$$k = F \cdot \min(50 \times 10^{-6} s, 10\ s)$$

$$k = 20 Hz \cdot 50 \times 10^{-6} s$$

$$k = 1 \times 10^{-3}$$

Which is rounded up to the next whole number so that

$$k = 1$$

We then determine n, the number of pulses that occur within time T. Note that a special case applies (use minimum of T and T_2) because the wavelength is 1064 nm, and we also note that for a small source, T_2 is 10 sec, the same as our exposure time, T.

$$n = F \cdot \min(T, T_2)$$

$$n = 20\ Hz \cdot 10\ s$$

$$n = 200$$

Since $k = 1$, we find from (3.c.) $n_{eff} = n$.

$$n_{eff} = 200$$

d. MPE_3 is next computed

$$MPE_3 = \frac{(n_{eff})^{-0.25} \cdot MPE_{TSP}}{k}$$

$$MPE_3 = \frac{(200)^{-0.25} \cdot 5.0 \times 10^{-6} \, J \cdot cm^{-2}}{1}$$

$$MPE_3 = 1.33 \times 10^{-6} \, J \cdot cm^{-2}$$

e. The limiting aperture diameter for an exposure duration of 50 microseconds ($t < t_{min}$) and 1064 nm is

$$D_f = 7.0 \, mm$$

f. The value of $Q_{MPE\text{-}3}$ is computed to be

$$Q_{MPE-3} = MPE_3 : H \cdot \frac{\pi \cdot D_f^2}{4}$$

$$Q_{MPE-3} = 1.33 \times 10^{-6} \, J \cdot cm^{-2} \cdot \frac{\pi \cdot (0.70 \, cm)^2}{4}$$

$$Q_{MPE-3} = 5.12 \times 10^{-7} \, J$$

Select Correct MPE.
Finally, we select the appropriate MPE value.

a. We create a table of MPE values written in terms of energy per pulse and corresponding limiting aperture diameter for each MPE.

$$Q_{MPE-1} = 9.6 \times 10^{-5} \, J \quad D_f = 7.0 \, mm$$

$$Q_{MPE-2} = 9.6 \times 10^{-5} \, J \quad D_f = 7.0 \, mm$$

$$Q_{MPE-3} = 5.12 \times 10^{-7} \, J \quad D_f = 7.0 \, mm$$

b. The limiting aperture diameter for each MPE is the same (D_f = 7.0 mm), so there is no need to compute Q_f for comparisons. We can select the smallest MPE to be used in all subsequent hazard analyses. In this case, MPE_3 is the applicable MPE. Our final set of parameters to use in these analyses is listed below.

Q_{MPE}	5.12 x 10^{-7} J
MPE	1.33 x 10^{-6} $J \, cm^{-2}$
Limiting Aperture Diameter (D_f)	7.0 mm

NOHD

The analysis required for conditions of no atmospheric attenuation is straight-forward. We apply Equation 8 and obtain the result below.

$$r_{HD} = r_0 + \frac{1}{\phi}\sqrt{\frac{-D_f^2}{\ln\left(1-\frac{Q_{MPE}}{Q_0}\right)} - a^2}$$

$$r_{HD} = 0.0cm + \frac{1}{1.0\times10^{-3}\,rad}\sqrt{\frac{-(0.7cm)^2}{\ln\left(1-\frac{5.12\times10^{-7}\,J}{0.5J}\right)} - (1.0cm)^2}$$

$$r_{HD} = 6.9\times10^5\,cm$$

OD
At 20 cm from the output aperture, the laser beam diameter can be approximated by 1.0 cm, as the divergence is small and the propagation distance is extremely short. The OD requirement can be computed using
Equation 6 and Equation 13.

$$Q_f = Q_0\left[1 - e^{-\left(\frac{D_f^2}{a^2+(r-r_0)^2\phi^2}\right)}\right]$$

$$Q_f = 0.5J\left[1 - e^{-\left(\frac{(0.7cm)^2}{(1.0cm)^2+(20cm)^2(1.0\times10^{-3}\,rad)^2}\right)}\right]$$

$$Q_f = 0.19J$$

$$D_\lambda = \log_{10}\left[\frac{Q_f}{Q_{MPE}}\right]$$

$$D_\lambda = \log_{10}\left[\frac{0.19 J}{5.12 \times 10^{-7} J}\right]$$

$$D_\lambda = 5.6$$

B. LHAZ Results

The MPE for a multiple-pulse exposure is computed by first assigning the proper values within LHAZ. Figure A1 illustrates the parameters as entered on the Laser Parameters worksheet.
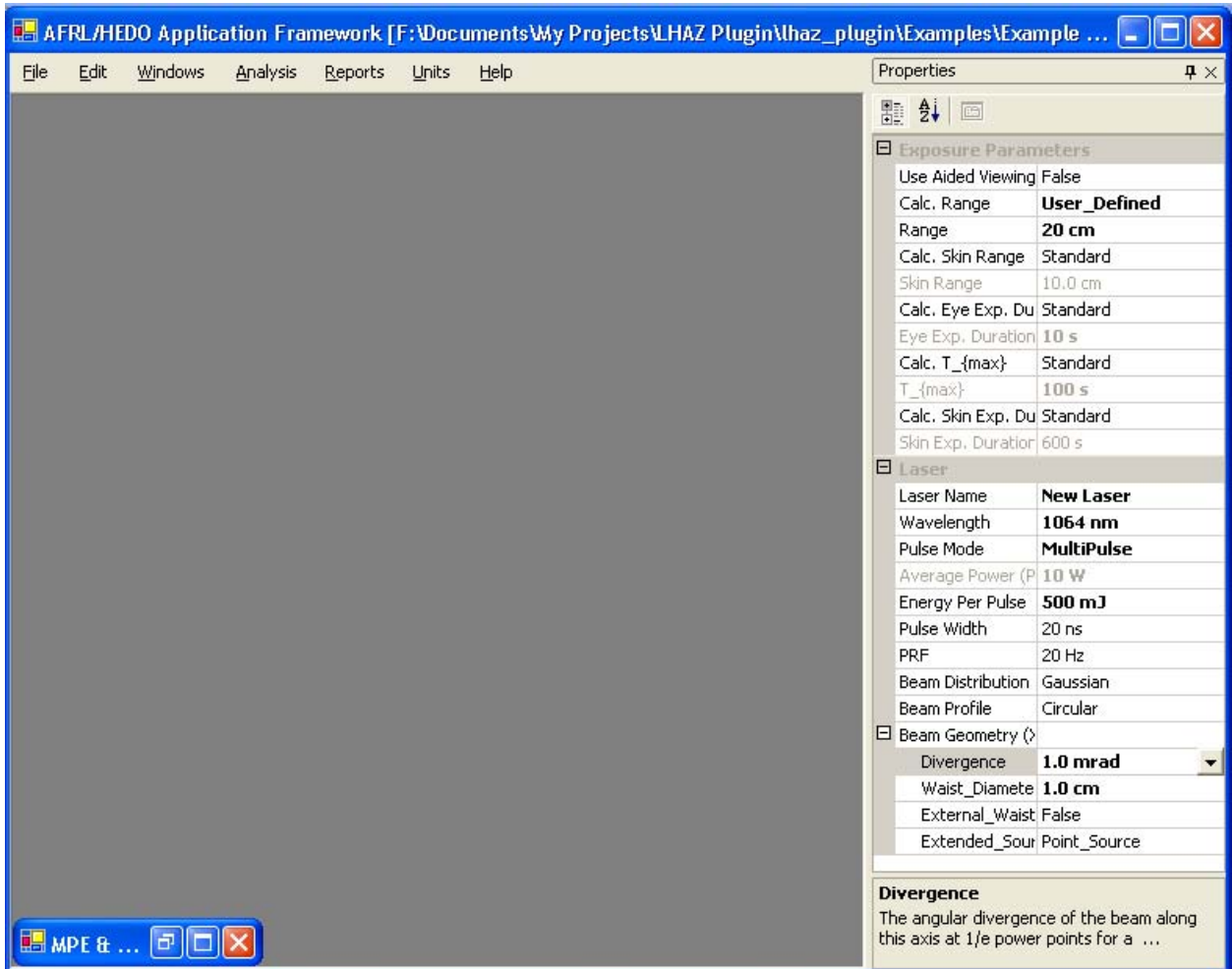
Figure A1: Laser Parameter Entries for Example 1.

MPE

The determination of MPE values can immediately be completed by viewing the *MPE and Classification* worksheet. The *Range* is set to 20 cm by the user, as specified by the problem statement. The *User Defined* Exposure Duration column indicates that the MPE for a 10.0 second exposure will be 1.330e-006 J/cm^2 in excellent agreement with the hand-computed value of 1.33 x 10^{-6} J/cm^2.
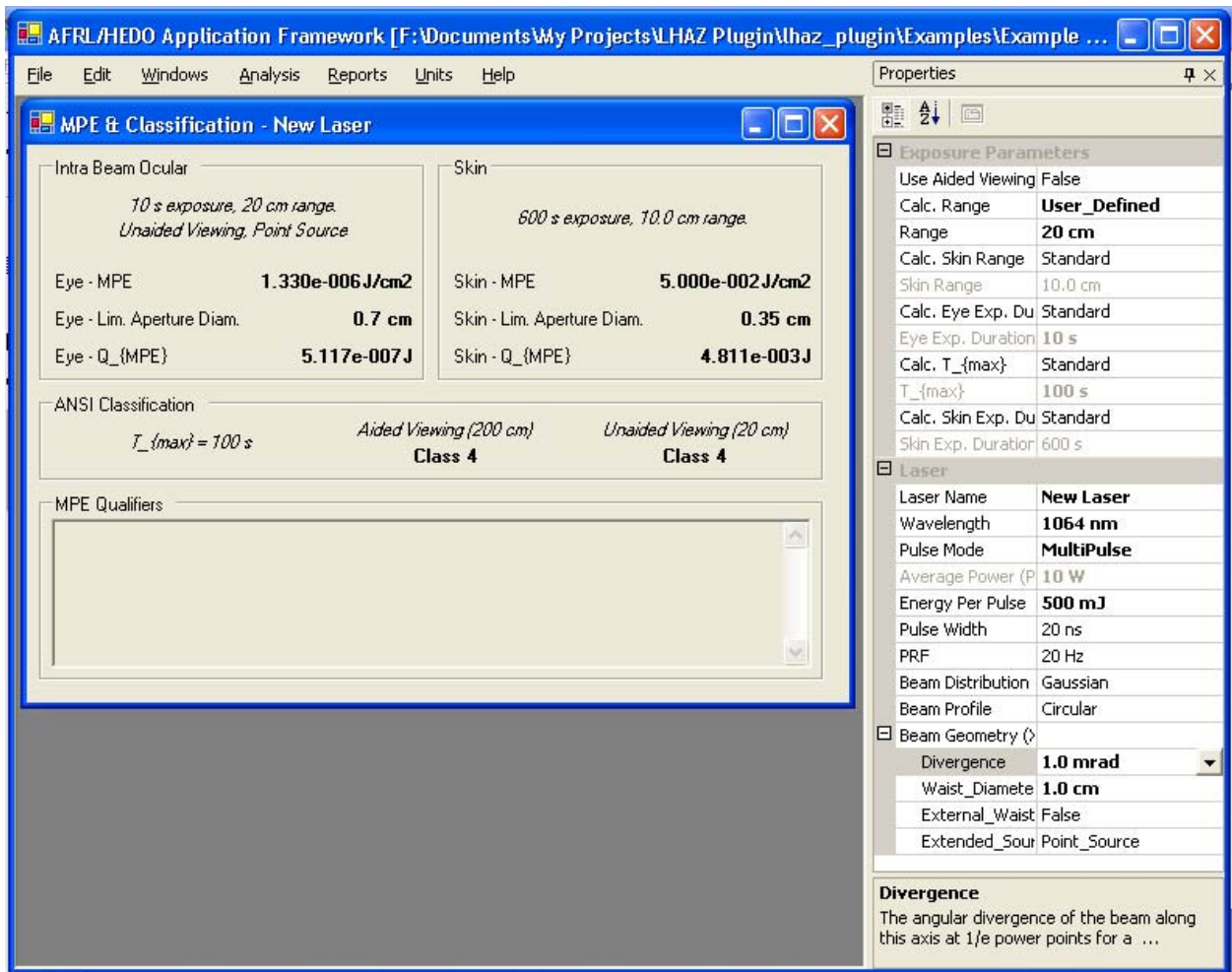
Figure A2: MPE Value Determination Results for Example 1.

NOHD

The NOHD value is found on the *NOHD and OD* worksheet. The exposure duration for the eye is confirmed to be 10 seconds. The atmospheric attenuation coefficient is set to zero, in accordance with the problem statement. The resulting NOHD is 6.92×10^5 cm for unaided viewing, in excellent agreement with the hand-computed value of 6.9×10^5 cm.

OD

The OD value is also computed on the *NOHD and OD* worksheet. In addition to the settings for the NOHD, *Range* and *Skin Range* are set to 20 cm. The resulting OD is computed by LHAZ to be 5.58 cm for unaided viewing, in excellent agreement with the hand-computed value of 5.6.
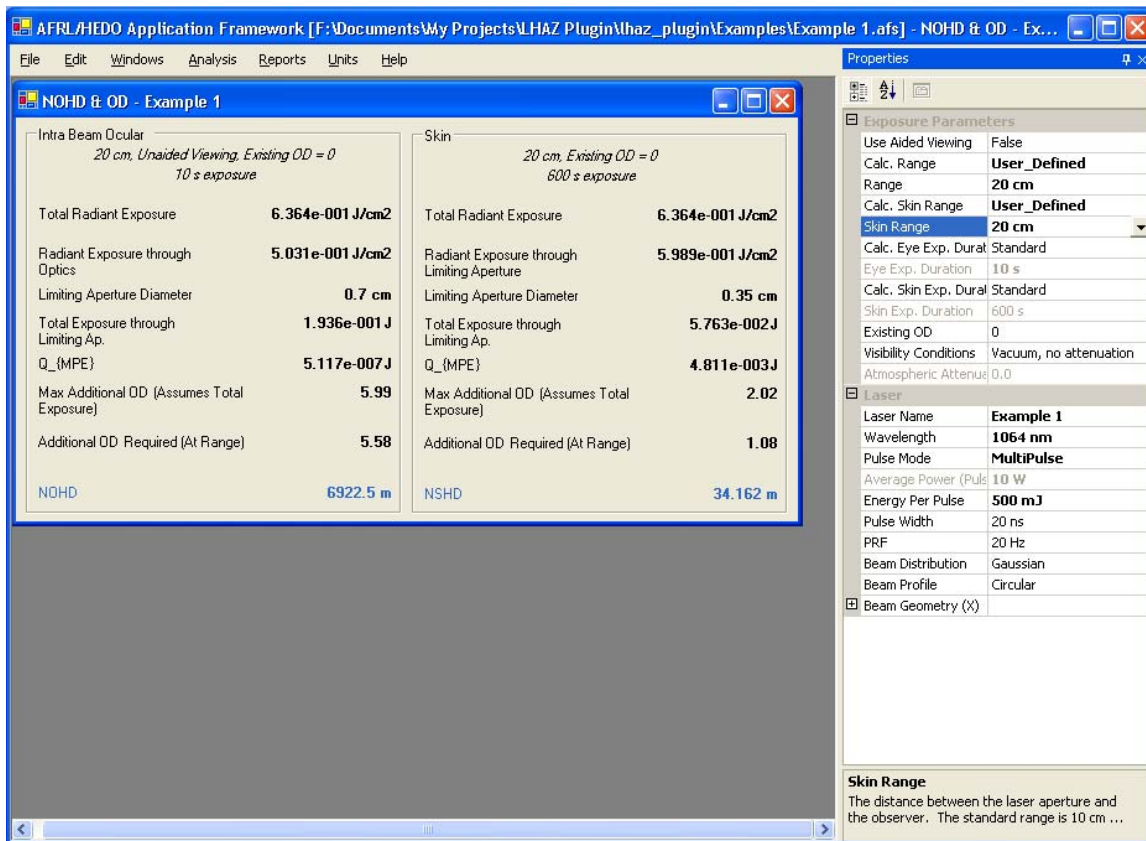
Figure A3. NOHD and OD Determination for Example 1.

A.2 EXAMPLE 2

Given a CW laboratory laser with the following parameters:

Parameter	Value	Parameter	Value
Wavelength (λ)	458 nm	Beam Waist Diameter (a)	1.0 mm
Average Power (Φ_0)	5.0 W	Beam Divergence (ϕ)	1.5 mrad
		Aperture to Beam Waist Distance (r_0)	100.0 cm
		Beam Profile/Shape	Circular - Gaussian
Source Size	0 cm	Aperture Diameter	2.0 mm

Compute the ocular MPE, and the OD required for viewing at a distance of 20 cm from the aperture. Assume that for unaided intra-beam viewing, a maximum time of anticipated direct exposure of T= 0.25 s, and no atmospheric attenuation or viewing optics. Also compute the NHZ and OD requirements for viewing the diffuse reflection of the laser beam from a target with a reflection coefficient ρ_λ of

0.8 at a wavelength of 458 nm. The laser output aperture is located 1.0 meter from the diffusely reflecting target, and the OD requirement for the exposure should be determined for an exposure distance of 50 cm for the target to viewer range (r_1). Assume that the maximum exposure time for the diffuse reflection is 30,000 seconds.

A. By Hand Results

Intra-beam MPE (0.25 s)

The MPE for a CW small source exposure is relatively simple to determine using Table 5a of the ANSI Z136.1 Standard. The relevant parameters and steps are shown below.

$$MPE : H = 1.8 \times t^{0.75} \times 10^{-3} J \cdot cm^{-2}$$

$$MPE : H = 1.8 \times (0.25)^{0.75} \times 10^{-3} J \cdot cm^{-2}$$

$$MPE : H = 0.64 \times 10^{-3} J \cdot cm^{-2}$$

This MPE expressed in Watts for a 0.25-second exposure is shown below.

$$MPE : E = \frac{MPE : H}{t}$$

$$MPE : E = \frac{0.64 \times 10^{-3} J \cdot cm^{-2}}{0.25s}$$

$$MPE : E = 2.56 \times 10^{-3} W \cdot cm^{-2}$$

The corresponding limiting aperture diameter for the laser wavelength and exposure duration is determined from Table 7 of the ANSI Z136.1 Standard.

$$D_f = 7.0 mm$$

And the MPE expressed in terms of Watts can be computed using Equation 4.

$$\Phi_{MPE} = MPE : E \cdot \frac{\pi \cdot D_f^2}{4}$$

$$\Phi_{MPE} = 2.56 \ W \cdot cm^{-2} \cdot \frac{\pi \cdot (0.7cm)^2}{4}$$

$$\Phi_{MPE} = 0.98 \times 10^{-3} W$$

Intra-beam OD

The OD requirement can be computed using Equation 5 and Equation 12.

$$\Phi_f = \Phi_0 \left[1 - e^{-\left(\frac{D_f^2}{a^2 + (r - r_0)^2 \phi^2} \right)} \right]$$

$$\Phi_f = 5.0W \left[1 - e^{-\left(\frac{(0.7cm)^2}{(0.1cm)^2 + (20cm)^2 \left(1.5 \times 10^{-3} rad\right)^2} \right)} \right]$$

$$\Phi_f = 5.0W$$

$$D_\lambda = \log_{10} \left[\frac{\Phi_f}{\Phi_{MPE}} \right]$$

$$D_\lambda = \log_{10} \left[\frac{5.0W}{0.98 \times 10^{-3} W} \right]$$

$$D_\lambda = 3.70$$

Diffuse Reflection NHZ

The computation of the NHZ from the diffuse reflection will require the use of Equation 27.

$$r_{NHZ-Diffuse} = \sqrt{\frac{\Phi_0 \cdot \exp\left(-\mu \cdot (r + r_1)\right) \cdot \rho_\lambda \cos\Theta_v}{\pi \cdot MPE}}$$

We begin the process of determining the NHZ by determining the MPE for a small-source exposure of 30,000 seconds at a wavelength of 458 nm. The small source MPE is determined from Table 5a and the factor C_B is needed in this case, determined from Table 6.

$$C_B = 10^{20(\lambda - 0.450)}$$

$$C_B = 10^{20(0.458 - 0.450)}$$

$$C_B = 1.445$$

$$MPE : E = C_B \times 10^{-4} W \cdot cm^{-2}$$

$$MPE : E = 1.445 \times 10^{-4} W \cdot cm^{-2}$$

The NHZ can next be computed using an assumption that the exposure will be a small source.

$$r_{NHZ-Diffuse} = \sqrt{\frac{5.0W \cdot 0.8 \cdot 1.0}{\pi \cdot 1.445 \times 10^{-4} W \cdot cm^{-2}}}$$

$$r_{NHZ-Diffuse} = 93.7 cm$$

The question next is: Is the beam spot on the target considered a small source (α less than 1.5 mrad) from a distance of 1.0 m. We apply $D_L = \sqrt{a^2 + (r - r_0)^2 \phi^2}$ Equation 1 to determine the beam diameter a the laser to target range (r).

$$D_\rho = \sqrt{a^2 + (r - r_0)^2 \phi^2}$$

$$D_\rho = \sqrt{(0.1 cm)^2 + ((100 cm) - (100 cm))^2 (1.5 \times 10^{-3} rad)^2}$$

$$D_\rho = 0.10 cm$$

At a distance of 93.7 cm, the beam diameter of 0.10 cm subtends an angle determined by Equation 26.

$$\alpha = \frac{D_\rho}{r_1}$$

$$\alpha = \frac{0.10 cm}{93.7 cm}$$

$$\alpha = 0.0011 \ rad$$

The resulting angle of 1.1 mrad means that the small source MPE does apply and our NHZ is 93.7 cm.

Diffuse Reflection OD
For a target-to-viewer range of 50cm, we must first determine the MPE for a source size determined using Equation 26. From our NHZ computation, we know that the beam diameter on the target is 0.1 cm.

$$\alpha = \frac{D_\rho}{r_1}$$

$$\alpha = \frac{0.10cm}{50cm}$$

$$\alpha = 0.002 \ rad$$

Since this will be considered an extended source (greater than 1.5 mrad), we must apply Table 5b to determine the MPE. We find that both thermal and photochemical limits must be computed and compared to determine the applicable MPE.

<div style="display: flex">

<u>Thermal MPE</u>

$$MPE: E = 1.8 \ C_E \ T_2^{-0.25} \times 10^{-4} W \cdot cm^{-2}$$

$$C_E = \frac{\alpha}{\alpha_{min}}$$

$$C_E = \frac{2.0mrad}{1.5mrad}$$

$$C_E = 1.333$$

$$T_2 = 10 \times 10^{(\alpha - 1.5)/98.5}$$

$$T_2 = 10 \times 10^{(2.0 - 1.5)/98.5}$$

$$T_2 = 10.1$$

$$MPE: E = 1.8 \ (1.33) \ \left(10.1_2^{-0.25}\right) \times 10^{-4} W \cdot cm^{-2}$$

$$MPE: E = 1.3 \times 10^{-4} W \cdot cm^{-2}$$

<u>Photochemical MPE</u>

$$MPE: E = C_B \ \times 10^{-4} W \cdot cm^{-2}$$

$$C_B = 10^{20(\lambda - 0.450)}$$

$$C_B = 10^{20(0.458 - 0.450)}$$

$$C_B = 1.445$$

$$MPE: E = 1.4 \times 10^{-4} W \cdot cm^{-2}$$

</div>

Of these two values, the "Thermal" MPE is the smaller, and so it is applied to the computation of the optical density requirement. The value of the optical density required for a safe exposure is then given by Equation 28.

$$D_\lambda = \log_{10}\left[\frac{E_{obs}}{MPE:E}\right]$$

Here we need the irradiance at the observer, which can be computed using Equation 24.

$$E_{Obs} = \frac{\Phi_0 \cdot \exp(-\mu \cdot (r + r_1)) \cdot \rho_\lambda \cos\Theta_v}{\pi r_1^2}$$

$$E_{Obs} = \frac{5.0W \cdot (1) \cdot (0.8) \cdot (1)}{\pi (50dm)^2}$$

$$E_{Obs} = 5.1 \times 10^{-4} W \cdot cm^{-2}$$

The OD requirement can now be computed.

$$D_\lambda = \log_{10}\left[\frac{5.1 \times 10^{-6} W \cdot cm^{-2}}{1.3 \times 10^{-4} W \cdot cm^{-2}}\right]$$

$$D_\lambda = 0.59$$

B. LHAZ Results

Intra-beam MPE (0.25 s)

The MPE for a CW small source exposure is relatively simple to determine using the MPE and Classification Worksheet after entering our laser parameters into the Laser Parameter worksheet of LHAZ. We obtain a small-source MPE of 2.598 x 10^{-3} W cm^{-2}. This is in good agreement with the value of 2.56 x 10^{-3} W cm^{-2} computed by hand. We note that the small discrepancy is due to two factors: rounding errors in our hand computations and the fact that LHAZ uses a non-rounded coefficient of 1.837380237 in the MPE computation, instead of the 1.8 prefix found in Table 5a of the ANSI Standard.

Intra-beam OD

The intra-beam OD requirement can be determined from the NOHD and OD worksheet. We verify that the viewing distance and exposure duration are correct and obtain an OD requirement of 3.70 OD. This agrees exactly with the value computed by hand of 3.70.

Diffuse Reflection NHZ

The diffuse reflection NHZ for a 30,000 second exposure is determined using the Diffuse/Specular Reflections worksheet. The results for Example 2 are shown in Figure A4. The NHZ computed using LHAZ is 93.492cm, while the value computed by hand is 93.7cm, a good agreement.
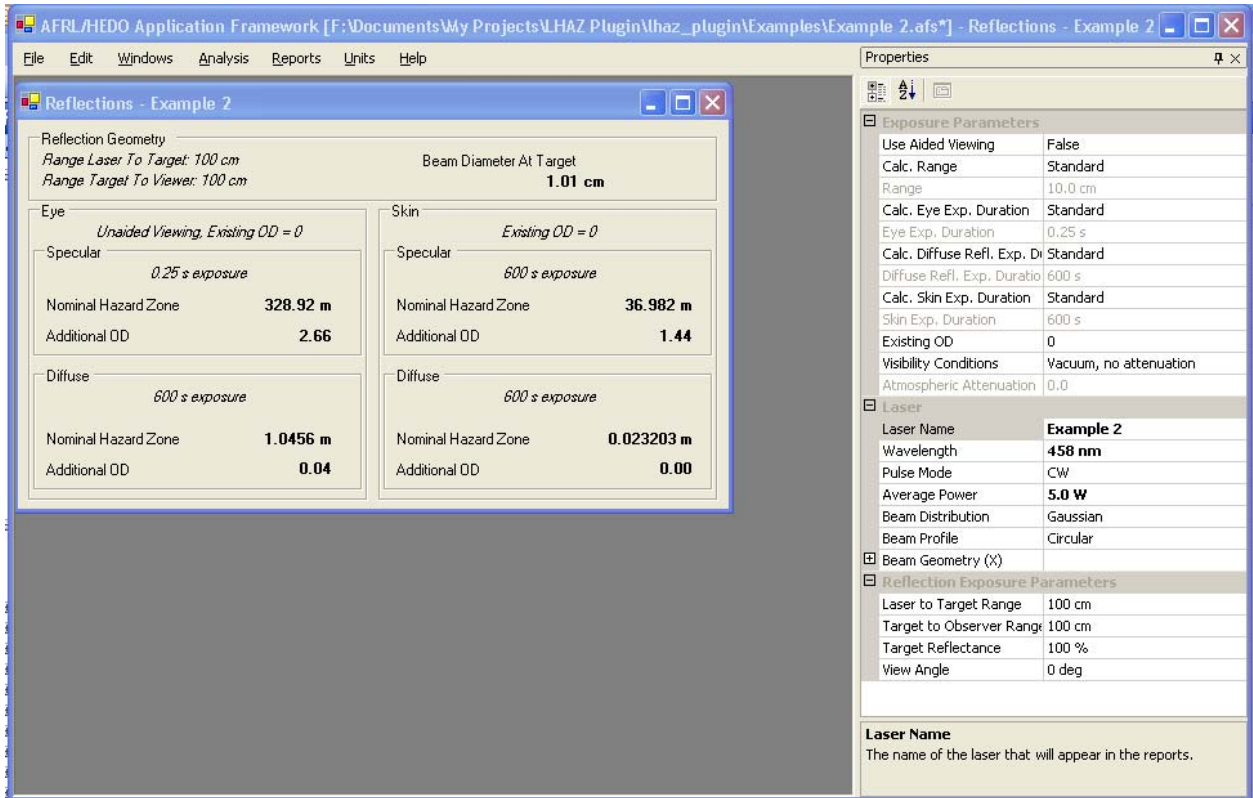
Figure A4: Diffuse Reflection Hazard Analysis Results for Example 2.

Diffuse Reflection OD

With LHAZ 4.2, the computation of this OD requirement for a target-to-viewer range of 50 cm is quite easy. We make sure that the target to viewer distance is set correctly along with other parameters. The resulting OD requirement for a 30,000-second exposure is 0.55. This result is in good agreement with the hand-computed value of 0.6. LHAZ values will typically be slightly smaller than those computed by hand, as LHAZ uses a slightly more accurate radiometric prediction of irradiance for a near-field exposure.

A.3   EXAMPLE 3

Given a CW alignment laser with the following parameters:

Parameter	Value	Parameter	Value
Wavelength (λ)	0.532 µm	Beam Waist Diameter	0.5 cm
Average Power (Φ_0)	1.0 mW	Beam Profile/Shape	Circular - Gaussian
Source Size	Small Source	Reference	Test Number 1985

. Classify the laser according to the ANSI Z136.1-2007.

A. By Hand Results

Since this is a CW laser, we will use the procedures that apply to CW lasers.

1. To determine T_{max} we note that no maximum exposure time is identified by the problem. We therefore apply the guidance of the ANSI Standard, and determine that $T_{max} = 30,000$ seconds.

2. The measurement aperture diameters (D_m) from Table 9 of the ANSI Standard are 7.0 mm for Condition 2 and 50.0 mm for Condition 1.

3. We next compute the Accessible Emission (Φ_m), which is the laser power or energy transmitted through the measurement aperture, for both Condition 1 (Φ_{m1}) and Condition 2 (Φ_{m2}). Since we know that the beam diameter at the smallest point for an exposure is $D_L = 0.5$ cm, we obtain

$$\Phi_m = \Phi_0 \left[1 - e^{-\left(\frac{D_m}{D_L}\right)^2} \right]$$

$$\Phi_{m2} = 1.0 \times 10^{-3} \ W \left[1 - e^{-\left(\frac{0.7}{0.5}\right)^2} \right]$$

$$\Phi_{m2} = 8.59 \times 10^{-4} \ W$$

$$\Phi_{m1} = 1.0 \times 10^{-3} \ W \left[1 - e^{-\left(\frac{5.0}{0.5}\right)^2} \right]$$

$$\Phi_{m1} = 1.0 \times 10^{-3} \ W$$

4. We next determine from Tables 8a or 8b of the ANSI Standard that the limiting aperture diameter (D_f) for λ = 0.532 μm and ocular exposure duration of $t = 30{,}000$ s yields

$$D_f = 7.0mm$$

5. From Table 5a and 6 of the ANSI Standard, we determine that the MPE for our laser wavelength (λ = 0.532 μm) and for an exposure time of $T_{max}= 30{,}000$ s is given by

$$MPE : E = 1 \times 10^{-3} W \cdot cm^{-2}$$

6. We next compute the AEL from the MPE in Step 5 and the limiting aperture diameter in Step 4.

$$Class\ 1\ \ AEL = MPE \cdot \frac{\pi \cdot D_f^2}{4}$$

$$Class\ 1\ \ AEL = 1 \times 10^{-3} W \cdot cm^{-2} \cdot \frac{\pi \cdot (0.7cm)^2}{4}$$

$$Class\ 1\ \ AEL = 3.85 \times 10^{-4} W$$

This is the Class 1 AEL for the laser.

7. Since $T_{max} > 0.25$ s in this problem and we have a visible laser ($\lambda = 0.532$ μm), we compute the MPE for a 0.25-second exposure using Table 5a of the ANSI Standard.

$$MPE : H = 1.8 \times t^{0.75} \times 10^{-3} J \cdot cm^{-2}$$

$$MPE : H = 1.8 \times (0.25)^{0.75} \times 10^{-3} J \cdot cm^{-2}$$

$$MPE : H = 6.4 \times 10^{-4} J \cdot cm^{-2}$$

$$MPE : E = \frac{MPE : H}{t}$$

$$MPE : E = \frac{6.4 \times 10^{-4} J \cdot cm^{-2}}{0.25}$$

8. From the MPE in Step 7 and the limiting aperture diameter in Step 4, we compute the Class 2 AEL for the laser.

$$Class\ 2\ \ AEL = 2.55 \times 10^{-3} W \cdot cm^{-2} \cdot \frac{\pi \cdot (0.7cm)^2}{4}$$

$$Class\ 2\ \ AEL = 9.8 \times 10^{-4} W$$

9. Since our laser wavelength is 0.532 µm, we compute the Class 3R AEL as:

$$Class\ 3R\ AEL = 5 \times Class\ 2\ AEL$$

$$Class\ 3R\ AEL = 5 \times 1 \times 10^{-3} W$$

$$Class\ 3R\ AEL = 4.9 \times 10^{-3} W$$

10. We now determine the Class 3B AEL for the wavelength of the laser. Since our

wavelength is 0.532 µm, we use the criteria:

a) (400 nm $\leq \lambda < 1400$ nm) An average power less than 500 mW (T ≥ 0.25

sec) and unable to produce more than 30 C_A mJ per pulse (for a single

pulse).

Since the laser is CW, we determine from the above statement that our Class 3B

AEL is given by:

$$Class\ 3B\ AEL = 500mW$$

Steps 11 – 13 determine if the laser is a Class 1 or 1M Laser (Class 1 AEL)

11. We next compare the Class 1 AEL from Step 6 to Φ_{m1} and Φ_{m2}.

$$\Phi_{m1} = 1.0 \times 10^{-3}\ W$$

$$\Phi_{m2} = 8.59 \times 10^{-4}\ W$$

$$Class\ 1\ AEL = 3.85 \times 10^{-4} W$$

Since both Φ_{m1} and $\Phi_{m2} >$ (Class 1 AEL), the laser is not Class 1 so we continue

with Step 13.

12. N/A

Steps 13 – 14 determine if the laser is a Class 2 or 2M Laser (Class 2 AEL). Class 2

specifications apply to visible lasers only (400 nm $\leq \lambda <$ 700 nm)

13. We next compare the Class 2 AEL from Step 8 to Φ_{m1} and Φ_{m2}.

$$\Phi_{m1} = 1.0 \times 10^{-3} \ W$$

$$\Phi_{m2} = 8.59 \times 10^{-4} \ W$$

$$Class \ 2 \ AEL = 9.8 \times 10^{-4} W$$

Since $\Phi_{m1} >$ (Class 2 AEL), we continue with Step 14.

14. For visible wavelengths (400 nm $\leq \lambda <$ 700 nm), if $\Phi_{m2} \leq$ (Class 2 AEL), compare

the Class 3B AEL from Step 10 to Φ_{m1}.

$$\Phi_{m1} = 1.0 \times 10^{-3} \ W$$

$$Class \ 3B \ AEL = 500 \times 10^{-3} W$$

Since $\Phi_{m1} \leq$ (Class 3B AEL), the laser is Class 2M so we STOP.

B. LHAZ Results

Classification

Entry of the laser parameters into LHAZ, and viewing of the MPE and
Classification worksheet should yield the results shown in Figure A5. We see that
LHAZ agrees with our classification analysis and lists Class 2M. We can also see
several of the AEL and MPE values computed along the way as part of the analysis.
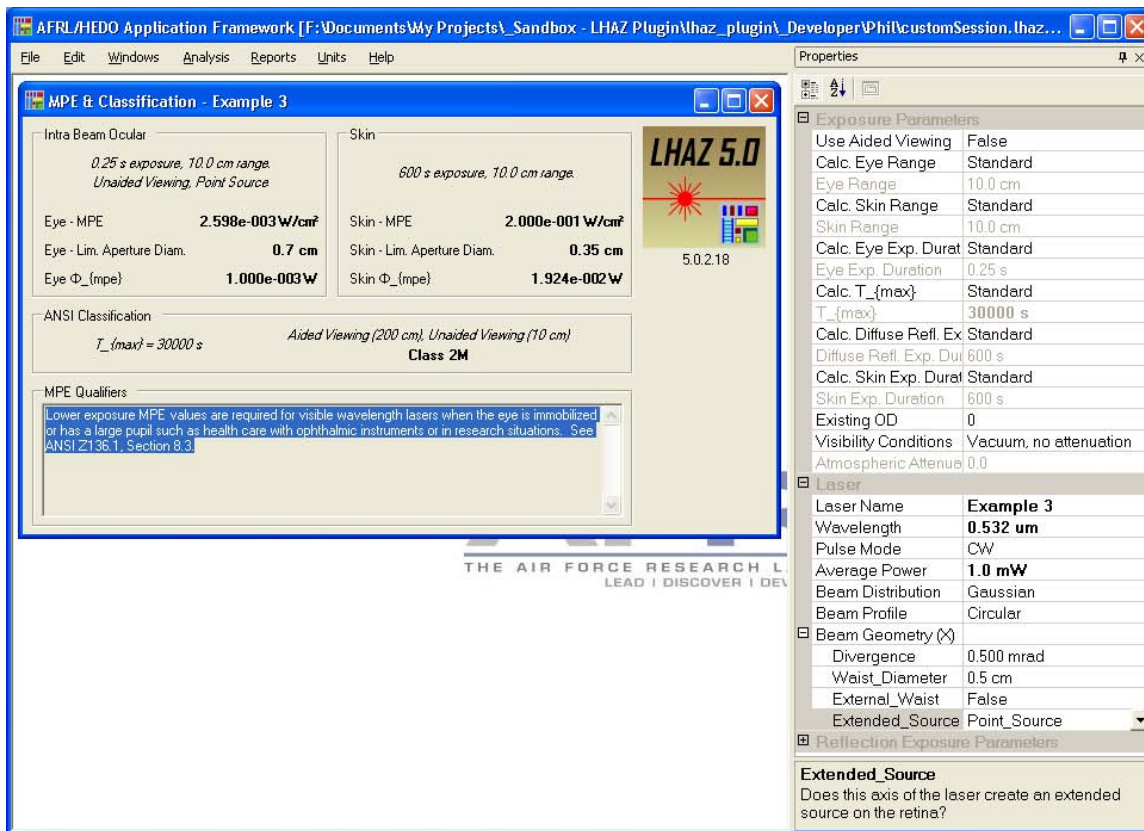
Figure A5: Classification Analysis Results for Example 3.

A.4   EXAMPLE 4

Consider a laser projector that uses a fiber-optic launch with a collimating lens. An observer of this laser sees a magnified image of the fiber tip as an extended source, which partially fills the output aperture (collimating lens) during an accidental exposure of 0.25 seconds. The observer is standing 2 meters away from the laser source.   The laser has the following parameters:

Parameter	Value	Parameter	Value
Wavelength (λ)	405 nm	Beam Waist Diameter (a)	2.5 cm
Average Power (Φ_0)	200.0 mW	Beam Divergence (ϕ)	0.5 mrad
		Aperture to Beam Waist Distance (r_0)	0.0 cm
		Beam Profile/Shape	Circular - Gaussian
Visual Angle Subtended (α)	4.0 mrad	Aperture Diameter	3.0 cm

Determine the MPE for this exposure and the OD required for safe viewing at a range of 2 meters.

A. By Hand Results

Intra-beam MPE (0.25 s)

The MPE for a CW extended source exposure requires the determination of source size. Since we have a constant-angle source, with a limiting diameter of the output aperture, we must determine the source size and if it over fills the output aperture. At a distance of 2 meters, the source diameter can be determined by Equation 2.

$$\alpha = \frac{D_s}{r}$$

$$D_s = \alpha \cdot r$$

$$D_s = 4.0 \times 10^{-3} \, rad \cdot 200 cm$$

$$D_s = 0.8 cm$$

Since the diameter of the source is less than the diameter of the output aperture, we use the diameter of the source for our hazard analysis. The MPE must be determined from Table 5b of the ANSI Z136l.1 Standard as we have an extended source. For an exposure duration of only 0.25 seconds, there are no dual limits to compute as in Example 2.

$$MPE : H = 1.8 \times C_E \times t^{0.75} \times 10^{-3} \, J \cdot cm^{-2}$$

$$C_E = \frac{\alpha}{\alpha_{min}}$$

$$C_E = \frac{4.0 mrad}{1.5 mrad}$$

$$C_E = 2.67$$

$$MPE : H = 1.8 \times 2.67 \times (0.25)^{0.75} \times 10^{-3} \, J \cdot cm^{-2}$$

$$MPE : H = 1.7 \times 10^{-3} \, J \cdot cm^{-2}$$

$$MPE : E = \frac{MPE : H}{t}$$

$$MPE : E = \frac{1.7 \times 10^{-3} \, J \cdot cm^{-2}}{0.25s}$$

$$MPE : E = 6.8 \times 10^{-3} \, W \cdot cm^{-2}$$

$$\Phi_{MPE} = MPE : E \cdot \frac{\pi \cdot D_f^2}{4}$$

$$\Phi_{MPE} = 6.8 \times 10^{-3} \, W \cdot cm^{-2} \cdot \frac{\pi \cdot (0.7cm)^2}{4}$$

$$\Phi_{MPE} = 2.6 \times 10^{-3} \, W$$

Optical Density Requirement

In order to compute the optical density requirement, we must know the amount of power transmitted by the limiting aperture at the exposure distance. This is

$$\Phi_f = \Phi_0 \left[1 - e^{-\left(\frac{D_f^2}{a^2 + (r - r_0)^2 \phi^2} \right)} \right]$$

computed using
Equation 5.

$$\Phi_f = \Phi_0 \left[1 - e^{-\left(\frac{D_f^2}{a^2 + (r - r_0)^2 \phi^2} \right)} \right]$$

$$\Phi_f = 200 mW \left[1 - e^{-\left(\frac{(0.7 cm)^2}{(2.5 cm)^2 + (200 cm)^2 \left(0.5 \times 10^{-3} rad \right)^2} \right)} \right]$$

$$\Phi_f = 15.1 mW$$

The optical density requirement is then computed using
Equation 12.

$$D_\lambda = \log_{10} \left[\frac{\Phi_f}{\Phi_{MPE}} \right]$$

$$D_\lambda = \log_{10} \left[\frac{\Phi_f}{\Phi_{MPE}} \right]$$

$$D_\lambda = \log_{10} \left[\frac{15.1 \times 10^{-3} W}{2.6 \times 10^{-3} W} \right]$$

$$D_\lambda = 0.76$$

B. LHAZ Results

Intra-Beam MPE (0.25s)

Entry of the laser parameters into LHAZ, and viewing of the *MPE and Classification* worksheet should yield the results shown in Figure A6. Note that it

is important to enter the source size on the Laser Parameters worksheet correctly, noting the source size entry in mrad. After entry of the 200 cm for Exposure Range, we obtain an Extended Source MPE of approximately 6.93 x 10^{-3} W cm^{-2}, in good agreement with the value computed by hand of 6.8 x 10^{-3} W cm^{-2}. This slight discrepancy is due primarily to the correction of rounding of the 1.8 in the MPE expression by the ANSI Standard to a value with more significant digits.
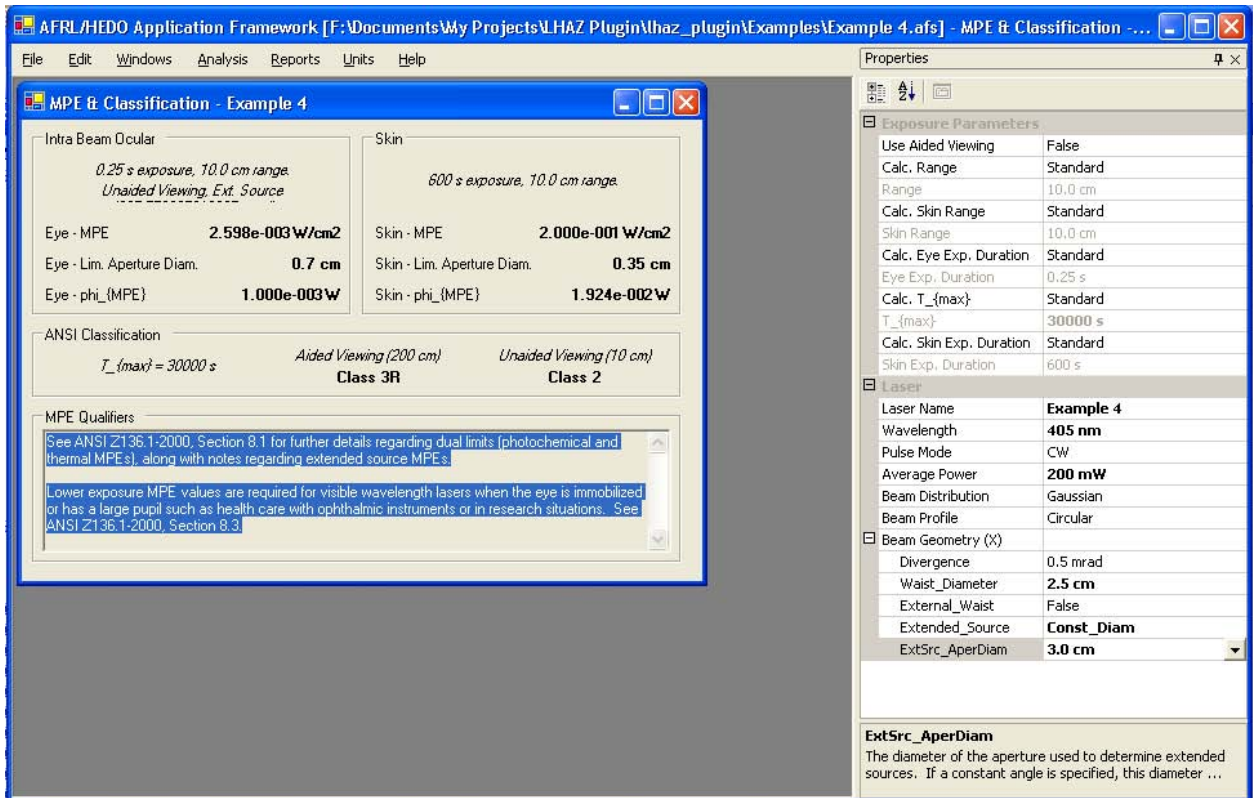
Figure A6. MPE Results Summary for Example 4.

Optical Density Requirement

LHAZ quickly provides us with the OD requirement summary that we need by viewing the *NOHD and OD* worksheet. We set the Range for OD Requirement value to 200 cm, and obtain a value of 0.71. This is in good agreement with the value of 0.76 obtained by hand computations. Again, there is a slight discrepancy due to the rounding correction by LHAZ and rounding errors in our by-hand computation. Figure A7 illustrates the parameters entered and results obtained using LHAZ.
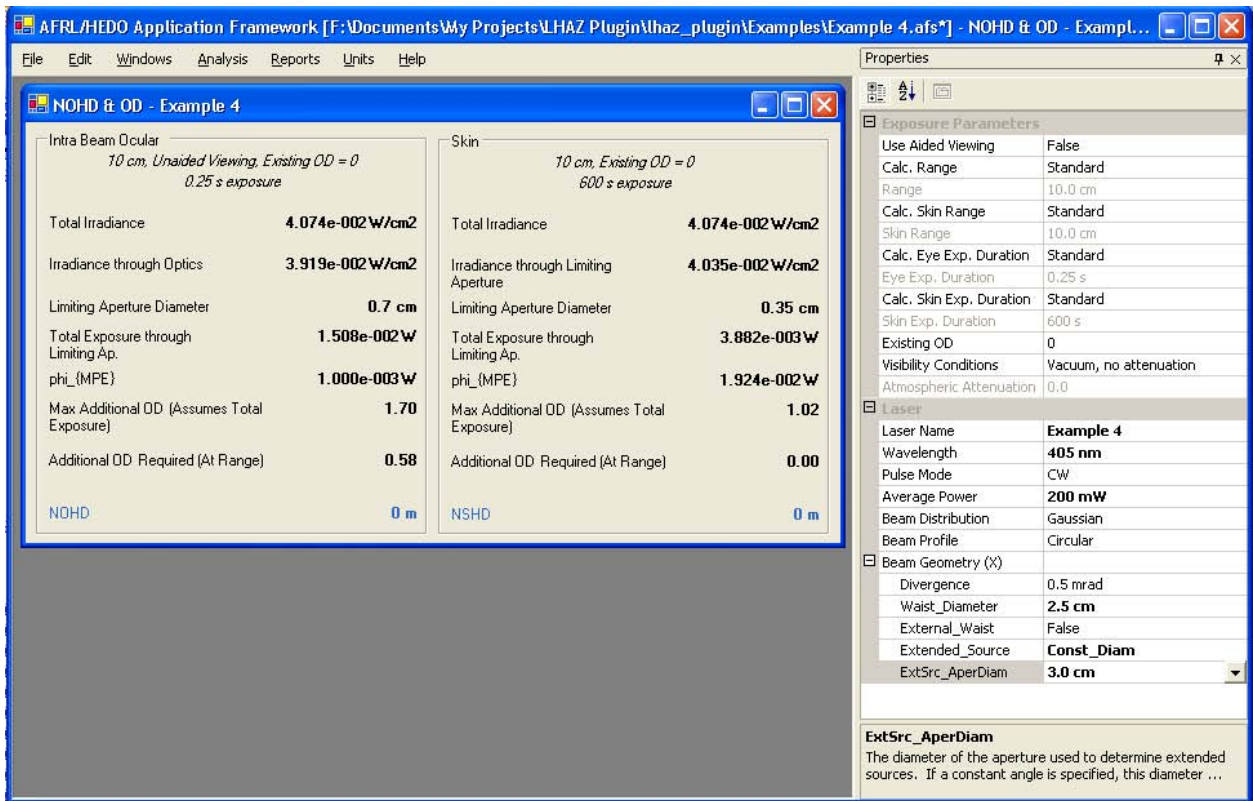
Figure A7. Analysis Results for OD Requirements in Example 4.

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APPENDIX B   COEFFICIENT VALUES

Table B-1. Reflection Coefficients (Fractional Reflectivity)*

	251 nm	305 nm	450 nm	550 nm	700 nm	800 nm	1000 nm	1500 nm	9000 nm
Water**	0.025	0.023	0.021	0.02	0.02	0.02	0.019	0.019	0.014
Steel**	0.329	0.372	0.544	0.549	0.576	0.580	0.631	0.708	0.929

	300-400 nm	400-800 nm	800-2600 nm	2.6-7μm
Snow	0.35	0.40	0.15	0.18
Sand	0.15	0.40	0.50	0.30

	500 nm	600 nm	840 nm	1780 nm
Asphalt	0.09	0.11	0.12	0.12
Concrete	0.15	0.41	0.48	0.56
Red Brick	0.15	0.41	0.48	0.56

* Forsythe, W.E., Smithsonian Physical Tables, Ninth Revised Ed., 1954.
** Normal incidence

Table B-2. Atmospheric Attenuation Coefficients (cm^{-1})*

λ	0 km	0-1km	1-2 km	2-3 km	304 km
337.1 nm	3.22 E-6	2.39 E-6	1.39 E-6	9.68 E-7	7.51 E-7
488.0 nm	1.59 E-6	1.35 E-6	6.69 E-7	3.62 E-7	2.33 E-7
514.5 nm	1.83 E-6	1.26 E-6	6.15 E-7	3.23 E-7	2.03 E-7
632.8 nm	1.46 E-6	9.85 E-7	4.58 E-7	2.21 E-7	1.26 E-7
694.3 nm	1.96 E-6	1.40 E-6	7.10 E-7	3.63 E-7	1.92 E-7
860 nm	1.07 E-6	7.18 E-7	3.22 E-7	1.45 E-7	7.49 E-8
1.06 μm	8.85 E-6	5.89 E-7	2.60 E-7	1.14 E-7	5.67 E-8
1.536 μm	6.47 E-7	4.30 E-7	1.89 E-7	8.16 E-8	3.93 E-8
3.392 μm	1.86 E-5	1.81 E-5	1.71 E-5	1.65 E-5	1.60 E-5
10.591 μm	3.68 E-6	3.32 E-6	1.91 E-6	1.16 E-6	7.64 E-7
27.90 μm	3.00 E-4	3.00 E-4	3.00 E-4	3.00 E-4	3.00 E-4
337.0 μm	2.03 E-4	1.60 E-4	9.66 E-5	5.58 E-5	2.87 E-5

*McClutchey, R.A., Fenn, R.W., Selby, J.E.A., Volt, F.E., and Garing, J.W., Optical Properties of the Atmosphere (Third Ed), AFCRL-72-0497, ERP 411, 1972.

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APPENDIX C   CLASSIFICATION PROCEDURE

C.1 PROCEDURE FOR CW (AND SINGLE PULSE) LASER CLASSIFICATION

2. Determine T_{max}. Consider the maximum exposure time from the design of the laser in addition to the time for T_{max} established in the ANSI Standard and summarized in the *Evaluation Parameters* section of this paper. The value of T_{max} is established from the minimum of these two values. For single pulse lasers, T_{max} is the duration of the pulse. If the pulse duration is ≥ 0.25 s, the output is regarded as a CW laser.

3. Determine the measurement aperture diameter (D_m) from Table 9 of the ANSI Standard. Use the value of T_{max} from Step1, and the laser wavelength for this determination. The measurement aperture diameters for Condition 1 and Condition 2 must both be considered for evaluation.

4. Compute the accessible emission (Φ_m), which is the laser power transmitted through the measurement apertures, for both Condition 1 (Φ_{m1}) and Condition 2 (Φ_{m2}), using Equation 5. For a single pulse, convert pulse energy to pulse power using Equation 8. The value of D_L for Condition 2 is usually determined at the distance indicating the greatest hazard, but no closer than 10 cm from the closest point of human access. For Condition 1, determinations of hazards from optically aided viewing (i.e., telescopes and binoculars) should be made at the distance indicating the greatest hazard, but no closer than 200 cm from the laser exit port, for all wavelengths (0.302 to 2.8 μm) that transmit through common optics.

5. Determine the limiting aperture diameter (D_f) for the wavelength of the laser and exposure duration of $t = T_{max}$. Tables 8a and 8b of the ANSI Standard contain values of D_f.

6. For the wavelength of the laser, compute the MPE for the exposure time of T_{max}. Use Table 5a or 5b of the ANSI Standard, depending upon which applies for the laser system. Table 6 contains supplementary information for computing the MPE.

7. Compute the AEL from the MPE in Step 5 and the limiting aperture diameter in Step 4 using Equation 7. This is the Class 1 AEL for the laser.

8. If the laser wavelength is 400 nm $\leq \lambda < 700$ nm, compute the MPE for the exposure time of 0.25 s. Use Table 5a or 5b of the ANSI Standard, depending upon which applies for the laser system. Table 6 contains supplementary information for computing the MPE. Note that there are no single pulse Class 2 lasers, with $t <$ 0.25 s

9. For visible wavelengths, compute the AEL from the MPE in Step 7 and the limiting aperture diameter in Step 4 using Equation 7. This is the Class 2 AEL for the laser. Note: The limiting aperture can be used from Step 4 because in the wavelength range of 400 nm to 700 nm, the limiting aperture diameter is constant for all exposure durations.

10. Compute the Class 3R AEL. The Class 3R AEL is computed as:

    a) Class 3R AEL = 5 x Class 2 AEL if (400 nm $\leq \lambda < 700$ nm)

    b) Class 3R AEL = 5 x Class 1 AEL if ($\lambda < 400$ nm or $\lambda \geq 700$ nm)

11. Determine the Class 3B AEL for the wavelength of the laser. These can be summarized as:

a) (180nm $\leq \lambda <$ 400 nm, 1400 nm $\leq \lambda <$ 1 mm) An average radiant power less than or equal to 0.5 W for an exposure time T $\geq$ 0.25 s, or a radiant energy less than or equal to 0.125 J within an exposure time T $<$ 0.25 s.

b) (400 nm $\leq \lambda <$ 1400 nm) An average radiant power less than or equal to 0.5 W for an exposure time T $\geq$ 0.25 s and a radiant energy less than or equal to the minimum of 0.03 C_A and 0.125 J per pulse. For this limit, pulses separated by less than t_{min} are to be considered one pulse. Note that C_A is determined from Table 6 of the ANSI Standard.

12. Compare the Class 1 AEL from Step 6 to Φ_{m1} and Φ_{m2} from Step 3. If both Φ_{m1} and $\Phi_{m2} \leq$ (Class 1 AEL), then the laser is Class 1 and STOP. Otherwise, for visible wavelengths (400 nm $\leq \lambda <$ 700 nm), continue with Step 12. For other wavelengths ($\lambda <$ 400 nm or $\lambda \geq$ 700 nm), continue with Step 13.

13. For visible wavelengths (400 nm $\leq \lambda <$ 700 nm), if $\Phi_{m1} >$ (Class 1 AEL), $\Phi_{m1} \leq$ (Class 2 AEL), and $\Phi_{m2} \leq$ (Class 1 AEL), then the laser is Class 1M and STOP. Otherwise continue with Step 14.

14. For other wavelengths ($\lambda <$ 400 nm or $\lambda \geq$ 700 nm), if $\Phi_{m1} >$ (Class 1 AEL), $\Phi_{m1} \leq$ (Class 3R AEL), and $\Phi_{m2} \leq$ (Class 1 AEL), then the laser is Class 1M and STOP. Otherwise continue with Step 16.

15. For visible wavelengths, compare the Class 2 AEL from Step 8 to Φ_{m1} and Φ_{m2}. If both Φ_{m1} and $\Phi_{m2} \leq$ (Class 2 AEL) then the laser is Class 2 and STOP. Otherwise continue with Step 15.

16. For visible wavelengths, if $\Phi_{m1} >$ (Class 2 AEL), $\Phi_{m1} \leq$ (Class 3R AEL), and $\Phi_{m2} \leq$ (Class 2 AEL), then the laser is Class 2M and STOP. Otherwise continue with Step 16.

17. Compare the Class 3R AEL from Step 9 to Φ_{m1} and Φ_{m2}. If both Φ_{m1} and $\Phi_{m2} \leq$ (Class 3R AEL) then the laser is Class 3R and STOP. Otherwise continue with Step 17.

18. Compare the Class 3B AEL from Step 10 to Φ_{m1} and Φ_{m2}. If both Φ_{m1} and $\Phi_{m2} \leq$ (Class 3B AEL), then the laser is Class 3B and STOP. Otherwise continue with Step 18. Note that Q_{group} and Q_{pulse} do not apply for a CW laser. However, for a single-pulse laser, the accessible emission for Condition 1 (Φ_{m1}) and Condition 2 (Φ_{m2}) needs to be converted to the quantities for the Class 3B AEL, using the following: $Q_{group} = Q_{pulse} = \Phi_m \times t$.

19. The laser or laser system is Class 4.

C.2 PROCEDURE FOR MULTIPLE PULSE LASER CLASSIFICATION

1. Determine T_{max}. Consider the maximum exposure time from the design of the laser in addition to the time for T_{max} established in the ANSI Standard and summarized in the *Evaluation Parameters* section of this paper. The value of T_{max} is established from the minimum of these two values. Note that T_{max} is not determined from the duration of a single pulse emitted, but the duration of the exposure which may contain several pulses.

2. Determine the measurement aperture diameter (D_m) from Table 9 of the ANSI Standard. For a multiple pulse system, measurement aperture diameters based upon the single pulse duration, the total exposure duration (T_{max}), and t_{min} must be

tabulated. This is because the ANSI *Three Rule Method* for determining AEL can produce multiple applicable AEL values. In the *Three Rule Method*, for Rule 1, D_m is determined from t. For Rule 2 (Average Power), D_m is determined from T_{max}. For Rule 3, D_m is determined from the greater of t and t_{min}.

3. Compute the accessible emission (Q_m), which is the laser energy transmitted through the measurement apertures, for both Condition 1 (Q_{m1}) and Condition 2 (Q_{m2}). There may be different applicable measurement aperture diameters for each of the three rules for determining MPE. The value of D_L for Condition 2 is usually determined at the distance indicating the greatest hazard, but no closer than 10 cm from the closest point of human access. For Condition 1, determinations of hazards from optically aided viewing (i.e., telescopes and binoculars) should be made at the distance indicating the greatest hazard, but no closer than 200 cm from the laser exit port, for all wavelengths (0.302 to 2.8 µm) that transmit through common optics.

4. Apply the *Three Rule Method* to compute the various AEL (per pulse) values for an exposure time of T_{max}. The *Three Rule Method* will determine three applicable AEL values. These are the Class 1 AEL values for the laser. This may not be a simple task, and the reader should reference our earlier tutorial on the subject.[4]

5. For visible wavelengths (400nm $\leq \lambda < 700$ nm), apply the *Three Rule Method* to compute the three AEL values (per pulse) for a 0.25-second exposure. These are the Class 2 AEL values for the laser.

6. Compute the Class 3R AEL values for the laser. The Class 3R AEL value is computed as:

   a) Class 3R AEL = 5 x Class 2 AEL if (400 nm $\leq \lambda < 700$ nm)

b) Class 3R AEL = 5 x Class 1 AEL if ($\lambda < 400$ nm or $\lambda > 700$ nm)

7. Determine the Class 3B AEL for the wavelength of the laser. These can be summarized as:

   a) (180nm $\leq \lambda < 400$ nm, 1400 nm $\leq \lambda < 1$ mm) An average radiant power less than or equal to 0.5 W for an exposure time $T \geq 0.25$ s, or a radiant energy less than or equal to 0.125 J within an exposure time $T < 0.25$ s.

   b) (400 nm $\leq \lambda < 1400$ nm) An average radiant power less than or equal to 0.5 W for an exposure time $T \geq 0.25$ s and a radiant energy less than or equal to the minimum of 0.03 C_A and 0.125 J per pulse. For this limit, pulses separated by less than t_{min} are to be considered one pulse. Note that C_A is determined from Table 6 of the ANSI Standard.

8. Compare each of the Class 1 AEL values from Step 4 to their corresponding values of Q_{m1} and Q_{m2} from Step 3. If Q_{m1} and $Q_{m2} \leq$ (Class 1 AEL), then the laser is Class 1 and STOP. Otherwise, for visible wavelengths (400 nm $\leq \lambda < 700$ nm), continue with Step 9. For other wavelengths ($\lambda < 400$ nm or $\lambda \geq 700$ nm), continue with Step 10.

9. For visible wavelengths (400 nm $\leq \lambda < 700$ nm), if $Q_{m1} >$ (Class 1 AEL), $Q_{m1} \leq$ (Class 2 AEL), and $Q_{m2} \leq$ (Class 1 AEL), then the laser is Class 1M and STOP. Otherwise continue with Step 11.

10. For other wavelengths ($\lambda < 400$ nm or $\lambda \geq 700$ nm), if $Q_{m1} >$ (Class 1 AEL), $Q_{m1} \leq$ (Class 3R AEL), and $Q_{m2} \leq$ (Class 1 AEL), then the laser is Class 1M and STOP. Otherwise continue with Step 13.

11. Compare the Class 2 AEL values from Step 5 to their corresponding values of Q_{m1} and Q_{m2} from Step 3. If Q_{m1} and $Q_{m2} \leq$ (Class 2 AEL), then the laser is Class 2 and STOP. Otherwise continue with Step 12.

12. If $Q_{m1} >$ (Class 2 AEL), $Q_{m1} \leq$ (Class 3R AEL), and $Q_{m2} \leq$ (Class 2 AEL), then the laser is Class 2M and STOP. Otherwise continue with Step 13.

13. Compare the Class 3R AEL values from Step 6 to Q_{m1} and Q_{m2} from Step 3. If Q_{m1} and $Q_{m2} \leq$ (Class 3R AEL) then the laser is Class 3R and STOP. Otherwise continue with Step 14.

14. Compute Φ_{avg} and $Q_{group,}$ using Equations 2 and 3 respectively, for a 0.25-second exposure for each Condition. Compare the Class 3B AEL values from Step 7 to Q_{m1} and Q_{m2}, Φ_{avg1} and Φ_{avg2}, and Q_{group1}, and Q_{group2}, as appropriate. If Q_{m1} and Q_{m2}, Φ_{avg1} and Φ_{avg1} , and Q_{group1} and Q_{group2}, as appropriate, are each less than the corresponding Class 3B AEL then the laser is Class 3B and STOP. Otherwise continue with Step 15.

15. The laser or laser system is Class 4.

C.3 SHORTCUTS:

- For higher power lasers ($\Phi_0 >$ 500 mW average power, or $Q_0 >$ 30mJ) do a quick check against Class 3B AEL. If Φ_m exceeds the Class 3B AEL we have saved several steps.

- For visible lasers, do a quick check of Φ_m against Class 2 AEL. This will save at least one step because it will immediately indicate if the laser is a more hazardous class than Class 2.

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APPENDIX D   LASER THREAT MODELING COMPONENT (LTMC) LIBRARY

The Laser Threat Modeling Components (LTMC) is the computational library that quantifies occupational and military threats from laser weapons systems. The library is available from AFRL/RHDO through the contact information listed in Appendix F of this manual.

Benefits:

- Laser safety calculation capability can be useful in mission planning and rehearsal, simulations, threat/vulnerability analyses, range test planning and training range safety

- Analysts and planners will be able to identify risks associated with laser hazards, and apply results to determine mission impact and improve future missions

- Modularized format allows existing software packages to use LTMC as a standardized computational base thus minimizing redundant code development

- Updates to data and models in modularized libraries requires little or no code changes to host applications

- User-friendly GUI facilitates use in numerous environments

Current USAF Projects incorporating LTMC: LHAZ 4.6, LHAZ 5.0, LAAST (Laser Analysis and Safety Tool), LRMS (Laser Range Management Software), LTAMPS (Laser Threat Analysis and Mission Planning Software)

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APPENDIX E   GLOSSARY OF TERMS

absorption - Transformation of radiant energy to a different form of energy by interaction with matter.

accessible emission limit (AEL) - The maximum accessible emission level permitted within a particular class of laser.

accessible optical radiation - Optical radiation to which the human eye or skin may be exposed for the condition (operation, maintenance, or service) specified.

alpha max (α_{max}) - The angular limit beyond which extended source MPEs for a given exposure duration are expressed as a constant radiance or integrated radiance. This value is defined as 100 mrad.

alpha min (α_{min}) - See limiting angular subtense.

aperture - An opening through which radiation can pass.

apparent visual angle - The angular subtense of the source as calculated from source size and distance from the eye. It is not the beam divergence of the source.

attenuation - The decrease in the radiant flux as it passes through an absorbing or scattering medium.

average power - The total energy imparted during exposure divided by the exposure duration.

aversion response - Movement of the eyelid or the head to avoid an exposure to a noxious stimulant or bright light. It can occur within 0.25 s, including blink reflex time.

beam - A collection of rays which may be parallel, divergent, or convergent.

beam diameter - The distance between diametrically opposed points in that cross-section of a beam where the power per unit area is 1/e (0.368) times that of the peak power per unit area.

blink reflex - See aversion response.

coherent - A light beam is said to be coherent when the electric vector at any point in it is related to that by any other point by a definite, continuous function.

collimated beam - Effectively, a "parallel" beam of light with very low divergence or convergence.

continuous wave (CW) - The output of a laser which is operated in a continuous rather than a pulsed mode. According to ANSI Standard Z136.1, a laser operating with a continuous output for a period ≥ 0.25 s is regarded as a CW laser.

controlled area - An area where the occupancy and activity of those within is subject to control and supervision for the purpose of protection from radiation hazards.

diffraction - Deviation of part of a beam, determined by the wave nature of radiation and occurring when the radiation passes the edge of an opaque obstacle.

diffuse reflection - Change of the spatial distribution of a beam of radiation when it is reflected in many directions by a surface or by a medium.

divergence (ϕ) - The increase in the diameter of the laser beam with distance from the exit aperture. The value gives the full angle at the point where the laser energy or irradiance is 1/e (36.8%) of the maximum value. For the purposes of this document, divergence is taken as the full angle, expressed in radians, of the beam diameter measured between those points which include laser energy or irradiance equal to 1/e of the maximum value (the angular extent of a beam which contains all of the radius vectors of the polar curve of radiant intensity that have length rated at 36.8% of the maximum). Sometimes this is referred to as beam spread.

ED-50 – Estimated dosage at which there is 50% probability of a minimal visible lesion (MVL) being detected in tissue exposed to a laser.

effective energy (Q_{eff}) - Energy, in joules, through the applicable measurement aperture.

effective power (Φ_{eff}) - Power, in watts, through the applicable measurement aperture.

electromagnetic radiation - The flow of energy consisting of orthogonally vibrating electric and magnetic fields lying transverse to the direction of propagation. X-ray, ultraviolet, visible, infrared, and radio waves occupy various portions of the electromagnetic spectrum and differ only in frequency, wavelength, and photon energy.

embedded laser - A laser with an assigned class number higher than the inherent capability of the laser system in which it is incorporated, where the system's lower classification is appropriate to the engineering features limiting accessible emission.

enclosed laser - A laser that is contained within a protective housing of itself or of the laser or laser system in which it is incorporated. Opening or removing of the protective housing provides additional access to laser radiation above the applicable MPE than possible with the protective housing in place (an embedded laser is an example of one type of enclosed laser).

energy (Q) - The capacity for doing work. Energy content is commonly used to characterize the output from pulsed lasers, and is generally expressed in joules (J).

extended source - A source of optical radiation with an angular subtense at the cornea larger than α_{min}. See *small source*.

focal length - The distance from the secondary nodal point of a lens to the primary focal point. In a thin lens, the focal length is the distance between the lens and the focal plane.

focal point - The point toward which radiation converges or from which radiation diverges or appears to diverge.

half-power point - The value on either of the leading or trailing edges of a laser pulse at which the power is one-half of its maximum value.

hertz (Hz) - The unit that expresses the frequency of a periodic oscillation in cycles per second.

intrabeam viewing - The viewing condition whereby the eye is directly exposed to all or part of a laser beam.

infrared - The region of the electromagnetic spectrum between the long-wavelength extreme of the visible spectrum (about 0.7 μm) and the shortest microwaves (about 1 mm).

infrared radiation - Electromagnetic radiation with wavelengths which lie within the range 0.7 μm to 1 mm.

irradiance (E) (at a point of a surface) - Quotient of the radiant flux incident on an element of the surface containing the point at which irradiance is measured, by the area of that element. Unit: watt per square centimeter (W/cm^2).

integrated radiance - The integral of the radiance over the exposure duration, expressed in joules-per-square-centimeter per-steradian (J$\cdot$cm^{-2}$\cdot$sr^{-1}).

intrabeam viewing - The viewing condition whereby the eye is exposed to all or part of a laser beam.

irradiance (E) - Radiant power incident per unit area upon a surface, expressed in watts-per-square-centimeter (W$\cdot$cm^{-2}). Synonym: *power density.*

joule (J) - A unit of energy. 1 joule = 1 watt x second.

Lambertian surface - An ideal surface whose emitted or reflected radiance is independent of the viewing angle.

laser - A device that produces radiant energy pre- dominantly by stimulated emission. Laser radiation may be highly coherent temporally, or spatially, or both. An acronym for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation.

laser safety officer (LSO) - One who has authority to monitor and enforce the control of laser hazards and effect the knowledgeable evaluation and control of laser hazards.

limiting angular subtense (α_{min}) - The apparent visual angle which divides intrabeam viewing from extended-source viewing.

limiting aperture diameter (D_f) - The maximum diameter of a circle over which irradiance and radiant exposure can be averaged.

maximum permissible exposure (MPE) - The level of laser radiation to which a person may be exposed without hazardous effects or adverse biological changes in the eye or skin. The criteria for MPE for the eye and skin are detailed in section 9 of ANSI Standard Z136.1.

minimal visible lesion (MVL) – Smallest detectable amount of damage to tissue from a laser exposure.

nominal hazard zone (NHZ) - The nominal hazard zone describes the space within the level of the direct, reflected, or scattered radiation when normal operation exceeds the applicable MPE. Exposure levels beyond the boundary of the NHZ are below the appropriate MPE level.

nominal ocular hazard distance (NOHD) - The distance along the axis of the unobstructed laser beam to the human eye beyond which the irradiance or radiant exposure during normal operation is not expected to exceed the appropriate MPE.

optical density (D_λ) - Logarithm to the base ten of the reciprocal of the transmittance. That is,

$$D_\lambda = - \log_{10} \tau_\lambda$$

where τ_λ is the transmittance.

NOTE: The higher the optical density, the lower the transmittance. Ten times the optical density is equal to the transmission loss expressed in decibels, e.g., an optical density of 0.3 corresponds to a transmission loss of 3 dB, i.e., 50 percent.

point source - No longer used. See *small source*.

power (Φ) - The rate at which energy is emitted, transferred, or received. Unit: watts (joules per second).

pulse duration (t) - The duration of a laser pulse; usually measured as the time interval between the half-power points on the leading and trailing edges of the pulse.

pulsed laser - A laser which delivers its energy in the form of a single pulse or a train of pulses. In ANSI Standard Z136.1, the duration of a pulse less than 0.25 s.

radian (rad) - A unit of angular measure equal to the angle subtended at the center of a circle by an arc whose length is equal to the radius of the circle. 1 radian = 57.3 degrees; 2 π radians = 360 degrees.

radiance (L) - Radiant flux or power output per unit area. Unit: watts per centimeter squared per steradian (W/cm^2/sr).

radiant energy (Q) - Energy emitted, transferred, or received in the form of radiation. Unit: joule (J).

radiant exposure (H) - Surface density of the radiant energy received. Unit: joules per square centimeter (J/cm^2).

radiant flux (Φ) - Power emitted, transferred, or received in the form of radiation. Unit: watt (W). Also called radiant power.

radiant intensity (I) (of a source in a given direction) - Quotient of the radiant flux leaving the source and propagated in an element of solid angle containing the given direction, by the element of solid angle. Unit: watts per steradian (W/sr).

reflectance (ρ) - The ratio of total reflected radiant power to total incident power. Also called *reflectivity*.

reflection - Deviation of radiation following incidence on a surface.

repetitively pulsed laser - A laser with multiple pulses of radiant energy occurring in sequence with a prf greater than or equal to 1 Hz.

small source - In this document, a source with an angular subtense at the cornea equal to or less than alpha-min (α_{min}), i.e., $\leq$ than 1.5 mrad. This includes all sources formerly referred to as "point sources" and meeting small-source viewing (formerly called point source or intrabeam viewing) conditions.

small-source viewing - The viewing condition whereby the angular subtense of the source, α_{min}, is equal to or less than the limiting angular subtense, α_{min}.

solid angle (Ω) - The three-dimensional angular spread at the vertex of a cone measured by the area intercepted by the cone on a unit sphere whose center is the vertex of the cone. It is expressed in steradians (sr).

source - A laser or a laser-illuminated reflecting surface.

specular reflection - A mirror-like reflection.

steradian (sr) - The unit of measure for a solid angle. There are 4π steradians about any point in space.

T_1 - The exposure duration (time) at which MPEs based upon thermal injury are replaced by MPEs based upon photochemical injury to the retina.

T_2 - The exposure duration (time) beyond which extended- source MPEs based upon thermal injury are expressed as a constant irradiance.

T_{max} - See *limiting exposure duration*.

t_{min} - For a pulsed laser, the maximum duration for which the MPE is the same as the MPE for a 1 ns exposure. For thermal biological effects, this corresponds to the "thermal confinement duration" during which heat flow does not significantly change the absorbed energy content of the thermal relaxation volume of the irradiated tissue (Example: t_{min} is 18 μs in the spectral region 0.4 to 1.05 μm and is 50 μs between 1.050 and 1.400 μm).

transmission - Passage of radiation through a medium.

transmittance (τ) - The ratio of total transmitted radiant power to the total incident radiant power.

ultraviolet radiation - Electromagnetic radiation with wavelengths shorter than those of visible radiation; for the purpose of the ANSI Z136.1 Standard, 0.18 to 0.4 μm.

visible radiation (light) - In the ANSI Z136.1 Standard, the term is used to describe electromagnetic radiation which can be detected by the human eye. This term is commonly used to describe wavelengths which lie in the range 0.4 to 0.7 μm.

watt (W) - The unit of power or radiant flux. 1 watt = 1 joule per second.

wavelength (λ) - The distance between two successive points on a periodic wave which have the same phase.

APPENDIX F   TECHNICAL SUPPORT

In case of an unknown error, LHAZ may notify you and terminate. If this happens, you have found a bug that we did not! Please try to reproduce the error, notify us at once, and be prepared to tell us how to reproduce the error.

If you suspect a computational error in the results provided by LHAZ, feel free to contact AFRL/RHDO. There is little chance that LHAZ will address every combination of laser parameters and analysis encountered. Also, we anticipate that with use, additional functionality will be requested, and newer versions will become available to provide the best laser hazard analysis available.

Please be sure to note your version and edition of LHAZ, as specified in the "Help, About AFRL/HEDO Application Framework…" pull-down menu at the top of the main application window.

Also, note that AFRL/RHDO will post any known problems and updates to LHAZ on the web site. AFRL/RHDO will continue to provide the most current version of LHAZ for the Department of Defense and its contractors.

To report errors in or problems with LHAZ,

To obtain LHAZ technical support and/or advice, or

To register your copy of LHAZ,

Contact:

> Air Force Research Laboratory
> Optical Radiation Branch (AFRL/RHDO)
> 2624 Louis Bauer Drive, Building 809
> Brooks City-Base, TX 78235-5128
>
> Laser Safety Hotline   1-800-473-3549
>   DSN 240-4784
>
> Laser Safety Mailbox Laser.Safety@brooks.af.mil
>
> Laser Safety Website https://afkm.wpafb.af.mil/LaserHotline (from .mil sites only)
>   The page lists any updates to the software and the release dates. Users can request an updated version of LHAZ or download the latest user's guide from this web site.

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APPENDIX G   CHANGES FROM EARLIER VERSIONS

G.1   SYNOPSIS OF CHANGES FROM LHAZ V4.2 TO V4.4

The update of LHAZ from version 4.2 to version 4.4 represents continuation of development according to combined planned LHAZ and Laser Threat Modeling Component (LTMC) software library schedules. These changes include many new features, improvements in computation precision, as well as additions requested by individual users. A few minor bugs have been identified and fixed in this revision.

The average user of LHAZ 4.4 will note few differences in the user interface or capabilities. Updates to the Standard Edition of LHAZ 4 include a new user interface for graph output such that multiple graphs can be displayed simultaneously. A simplified menu for producing a default hazard analysis report has been included. Also, an option to import files from version 3.0 of LHAZ has been incorporated.

The Professional Edition of LHAZ 4.4 has again expanded the advanced capabilities for laser threat analysis. Updates in the LTMC software libraries have allowed for a user interface to the complete LELAWS 3.0 accredited damage assessment models published in 1993. AFRL/RHDO has completed a migration of these libraries from FORTRAN to C++ in the LTMC libraries.   Merged with the existing capabilities of LTMC, this allows a user to now incorporate probabilities of exceeding multiple hazard or threat threshold types while considering atmospheric scintillation, beam bore sight error, damage threshold probability functions, and system jitter.

Other changes to LHAZ that may be noted by the more experienced user will include small differences in hazard distances computed for non-circular beam types. Numerical methods that are more accurate and avoid the use of approximations in exposure levels have been implemented. Also, more accurate estimates of the "worst case" exposure distance have been included which take into account atmospheric attenuation. Users will also note a few areas which include more detailed summaries of exposure levels used in optical density (OD) computations.

Minor bug fixes include updates to the user interface to clarify wording, functionality, or behavior of default parameters, such as the wavelength ranges within the graphs. Also, minor changes in default report templates have been included. No changes representing erroneous computational results were implemented.

G.2   SYNOPSIS OF CHANGES FROM LHAZ V4.0 TO V4.2

The updates of LHAZ from version 4.0 were primarily user-requested enhancements, including an expanded LHAZ 4.2 PROFESSIONAL edition used by expert analysts. The standard edition updates included the addition of an atmospheric attenuation coefficient computation based upon visibility conditions. Users may now set the units in which hazard distances are displayed. The new context-sensitive status bar provides users with a brief description of parameters as they are entered. Also added to LHAZ were several new graph types.

The Professional Edition of LHAZ 4.2 greatly expanded the advanced capabilities for laser hazard and threat analysis. Incorporating the new features of the Laser Threat Modeling

Component (LTMC) software libraries, LHAZ 4.2 provides the detailed estimates of the threshold for ocular damage (Minimal Visible Lesion ED-50 Estimates). Also included are vision models for the determination of target obscuration from visible-wavelength lasers. These provide separate worksheets, which include hazard distance calculations and the associated report-generation capabilities.

Addressed in the update to LHAZ 4.2 are several bugs identified by users of LHAZ 4.0. These include a change in the laser classification procedure, which applied the aided viewing transmittance to unaided viewing conditions. The correction for unaided viewing will increase the hazard classification of some UV and far-IR lasers.

Other bugs appeared in several graphs using a logarithmic X-axis scale. The first point in the series would be obviously inaccurate. Another significant bug addressed was in the computation of the limiting aperture in certain UV-wavelength multi-pulse laser conditions. This did not significantly affect the hazard analysis, except in the case of small beam exposures. The input field for the laser beam parameters in the case of elliptical or rectangular beams was corrected to allow input values under all circumstances. In version 4.0, a bug prevented the user from changing the values from their defaults.

Finally, several minor changes in the behavior of LHAZ 4.2 compared to LHAZ 4.0 have been implemented. The most significant of these is the dependence of MPE and AEL graphing on the user-defined exposure time from the MPE page. The exposure time previously was based upon the exposure time from the NOHD-OD worksheet. In order to clarify the exposure time upon which the graph is based, the exposure time used was added to the graph title.

Users will also note that parameter entry fields now change to yellow in color when parameters are entered. Also, when aided viewing conditions are selected, a binocular icon appears in the lower right corner on the status bar. When the OD worn by the observer is set to any value greater than zero, a person with laser eye protection appears on the status bar. These icons remind you of the current viewing conditions while on any worksheet. Other minor changes appear in the sections that follow. This user's guide contains illustrations from version 4.2 of LHAZ along with the explanations of functionality. Changes from version 4.0 are pointed out when possible.

G.3   SYNOPSIS OF CHANGES FROM LHAZ V3.0 TO V4.0

The motivation for the development of LHAZ Version 4 was the release of the revised ANSI Standard for the Safe Use of Lasers (ANSI Z136.1-2000). The changes between ANSI Z136.1-1993 (upon which LHAZ V3.0 is based) and the new release were significant enough to require a new release of LHAZ.

The basic operation and capabilities of the program have been significantly revised, primarily to provide for operation under a Microsoft Windows ™ operating system. Expanded computation capabilities provide an increased number of variables which can be assigned for a given laser exposure, and an expanded reporting capability, including graphical representations of hazard analyses, and report templates which can produce a variety of file formats.